Report to the Okanogan & Wenatchee National Forests on the Results of the Twentymile Planning Area Fire History Research

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ABSTRACT

The Twentymile Planning Area, located on the Okanogan and Wenatchee National Forests, was divided into thirteen polygons within the low and mixed-severity fire-regimes where a total of 111 individual fire years were cross-dated from 409 fire-scar samples. The dominant tree species are a mix of Douglas-fir (*Pseudotsuga menziesii*) and ponderosa pine (*Pinus ponderosa*) with lesser amounts of lodgepole pine (*Pinus contorta*), subalpine fir (*Abies lasiocarpa*), and Engelmann spruce (*Picea engelmannii*). The earliest fire discovered was in 1342, however, the "period of reliability" (Touchan et al. 1996) dates from 1660 to 1889 ("pre-suppression era").

Weibull median fire frequency intervals (WMFFI) were variable across most of the Twentymile planning area with analysis polygons averaging 16.1 years during this era. Polygons ranged from 9.5 years in Polygon 5 (low severity) to 43.4 in Polygon 11 (mixed severity). Elevation plays an important role in fire frequency in the Twentymile area. In general, as elevation increases, fire frequency lengthens. Elevation is shown to be a factor affecting frequency. Also, there is connectivity of disturbance between low elevation and high elevation forests.

Area burned in each fire within the sampled portion of the Twentymile area averaged 1,502 acres. Fires within sampled polygons typically burned from 33 to 72 percent of those areas. The largest fire was in 1843, burning 6,749 acres or 91% of the thirteen sampled polygons. There were 11 large fires that burned

greater than 25% of the total sampled area during the pre-suppression era. After 1889, there has been a dramatic change in the fire regime in sampled polygons with only 2 recorded fire burning 11 acres in 1914 and 15 acres in 1973.

1. INTRODUCTION

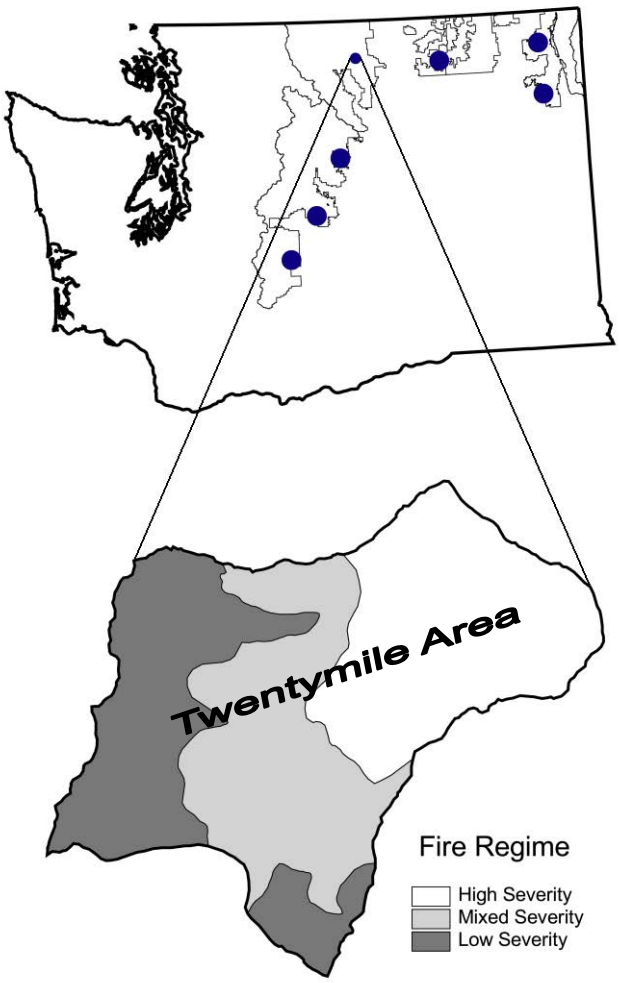


Figure 1. Twentymile Planning Area's location among six other fire-history sites examined by Everett et al. 2000; Schellhaas et al. 2000a, 2000b, & 2002; and Keenum (in prep.) on the Colville, Okanogan, and Wenatchee National Forests. Estimated coverage of fire regimes are also shown. The high severity portion was analyzed by Schellhaas et al. (2001).

The historical fire-regimes were analyzed in the Twentymile Planning Area of the Methow Valley Ranger District. The entire planning area totals 15,492 acres in size and is located in north-central Washington state, approximately 15 miles north of the town of Winthrop (Figure 1). The Twentymile Planning Area is bounded on the west by the Chewuch River and includes all or portions of Twentymile Creek, Leroy Creek, N. Fork Boulder Creek, Brevicomis Creek, Junior Creek, and Bromas Creek drainages. Approximately 30% of the Twentymile area can be classified as a low-severity fire-

regime, 30% as mixed severity, and 40% high severity. Most of the high-severity portions of Twentymile are found in subalpine forests that were analyzed by Schellhaas et al. (2001).

The broad range in elevation from 2,200 to 6,700 feet allows for the analysis of historical fire-regimes within a variety of forest conditions that are associated with increasing elevation. In general, increases in elevation at Twentymile are associated with lower evapotransporation rates and higher precipitation. Elevation may then be used as a surrogate for understanding the role of moisture on forest species and stand structures that affect fire frequency. Lower-elevation forest types are dominated by a mix of Douglas-fir (*Pseudotsuga menziesii*) and ponderosa pine (*Pinus ponderosa*) with lesser amounts of lodgepole pine (*Pinus contorta*). On north aspects, higher elevations, and where cooler more mesic conditions exist, Douglas-fir, lodgepole pine, Engelmann spruce (*Picea engelmannii*) and subalpine fir (*Abies lasiocarpa*) are present and ponderosa pine is rarely found.

Fire history is a function of forest type, topography, microclimate, ignition source, and past disturbance. Knowledge of fire history provides insight into stand structure and species composition that likely existed historically. Land managers can use this information to help create, restore, and maintain sustainable vegetation patterns. The inherent fire disturbance regime is an important reference point to assess changes in vegetative patterns and the

associated risks to catastrophic fire that have resulted from livestock grazing, timber harvest, and decades of fire suppression (Finch 1983, Agee 1994, Ohlson 1996, Wright 1996, Everett et al. 2000, Schellhaas et al. 2000a & 2000b, Keenum [in prep.]).

Research on the Colville, Okanogan, and Wenatchee National Forests has shown that stand structure and species composition in ponderosa pine, Douglas-fir, and grand fir (*Abies grandis*) forests have dramatically changed as inherent disturbance regimes have been altered (Finch 1983, Agee 1994, Ohlson 1996, Wright 1996, Everett et al. 2000, Schellhaas et al. 2000a & 2000b, Keenum [in prep.]). In the absence of fire, forests in these vegetation series have progressed further along successional trajectories. Fire regimes have changed from frequent low or mixed-severity towards a less frequent, but higher-severity (stand replacement) pattern.

The goal of this analysis was to describe historical fire-regimes in terms of frequency, extent, and severity to provide information that will assist forest planners in future management. The extensive range in elevation within the Twentymile Planning Area and the existing subalpine study (Schellhaas 2001) provide a unique opportunity to investigate the association of fire occurrence and magnitude to a gradient in elevation. These results will also fill a spatial gap to link a series of fire-history studies completed in other forests of eastern Washington, extending from the Colville National Forest to the southern end of

the Wenatchee National Forest (Figure 1). In addition, these data will be analyzed as part of a regional fire/climate project in cooperation with the University of Washington.

2. FIRE HISTORY TERMINOLOGY AND CONCEPTS

Researchers report results of fire history studies using specialized terminology. Without an understanding of fire history terms and concepts, it can be difficult to interpret the results of a study, compare results from different studies, or develop management options based on the results.

2.1 Fire Frequency

The occurrence of fire over time is generally described as fire frequency and is an important concept when comparing fire history information between various investigations. The number of years between two successive fires has commonly been described by researchers as; fire interval, fire-free interval or fire return interval.

The arithmetic mean of all fire-free intervals determined within a designated area during a selected time period is referred to as the mean fire-free

interval (MFFI). Although fire interval distributions have traditionally been described utilizing the MFFI, a better statistic to describe fire regimes may be the Weibull median fire-free interval (WMFFI). Frequent fire-regimes include fire-free interval distributions that are typically skewed (not normal or bell shaped but having one tail longer than the other). Because of this inclination, Grissino-Mayer (1995a) suggests that the WMFFI may be a more accurate metric for characterizing the central tendency of fire interval distributions. For this study, we have chosen to follow the terminology used in the FHX2 fire history analysis software developed by Grissino-Mayer (1995b).

2.2 Point vs. Area Estimations of Fire Frequency

Point-based and area-based fire frequencies are two separate concepts necessary to fully understand and evaluate fire history investigations. Point frequency is the mean or median fire interval at a single point (an individual scarred-tree) on the landscape. Point frequencies can also be expanded to include data from several neighboring scarred trees since a single tree may not always record every fire and succeeding fires may burn off older scars. Agee (pers. comm.) recommends sampling three to five scarred trees in close proximity (within < 3 acres) to derive an accurate estimate of fire frequency at an individual location. An area frequency on the other hand, characterizes the mean interval between fires that burned some portion of, but not necessarily the entire

sampled area. Point-based estimates of fire intervals are inherently longer than those attained from area estimates (Kilgore and Taylor 1979).

It is imperative to recognize the size of the area on which the estimated fire frequency is based. As the size of a sampled area increases, fire frequency typically decreases. Area fire-frequency determined from samples gathered across large landscapes is generally inappropriate to establish recurrent fire effects at smaller, stand levels. To reiterate, area frequencies define the occurrence of fire somewhere, but usually not throughout the entire area. As the sampled area increases in size or heterogeneity (i.e. topography, forest types, aspect, etc.), variability of fire frequency distributions becomes more pronounced. Conversely, point-based fire-frequencies, especially when validated by multiple scar samples taken from several proximate trees, provide specific evidence regarding the periodicity of repeated fires and the effects of those fires at a known point on the landscape.

2.3 Fire Regimes

A fire regime is a complex system of cycles and patterns of fire influenced by factors including species composition (overstory and understory), topography, and climate. All the factors of a fire regime are expressed in fire frequency, fire extent, fire intensity, and fire severity. Intensity refers to the heat and duration

produced by a fire while severity refers to a fire's effect on vegetation (Agee 1993).

A regime is complicated by the varying degrees of frequency, size, intensity, and severity that can occur but in general, three types of fire regimes are recognized based on the outcome of the regime: low-severity [non-lethal], mixed-severity, and high-severity [lethal] (Agee 1999). Here the "non-lethal/lethal" attribute refers to fire's effect on the overstory component of a forest.

Low-severity regimes are typified by fire-tolerant tree species with thick bark and open crowns. In the Inland Pacific Northwest these species primarily include ponderosa pine and western larch. Forests within the low-severity regime are drier and have frequent, low-intensity fire which maintain an open "park-like" appearance (Gorman 1899).

High-severity regimes usually are the result of longer time periods between fires. These longer intervals allow for denser forest structure, the establishment of fire-intolerant species, and higher fuel accumulation that can result in lethal stand-replacing fires. Species composition in these typically wetter forests tends toward later successional stages.

As the name implies, mixed-severity regimes are typified by a combination of low severity and high-severity fires. This regime is the most complex of all resulting in fragmented landscapes in varying degrees of succession. Normally, areas experiencing the higher-severity burns are in moister, cooler areas with longer fire return intervals (i.e. riparian areas, north-facing slopes, higher elevations). This contrasts with drier, warmer areas where frequent fire curtailed tree density and fuel buildup and lower fire intensity maintained overstory trees.

Note that the above description of fire regimes is meant to be viewed on a landscape level and that it should be recognized that both low or high-severity fire can occur at any one point within the landscape, under any regime.

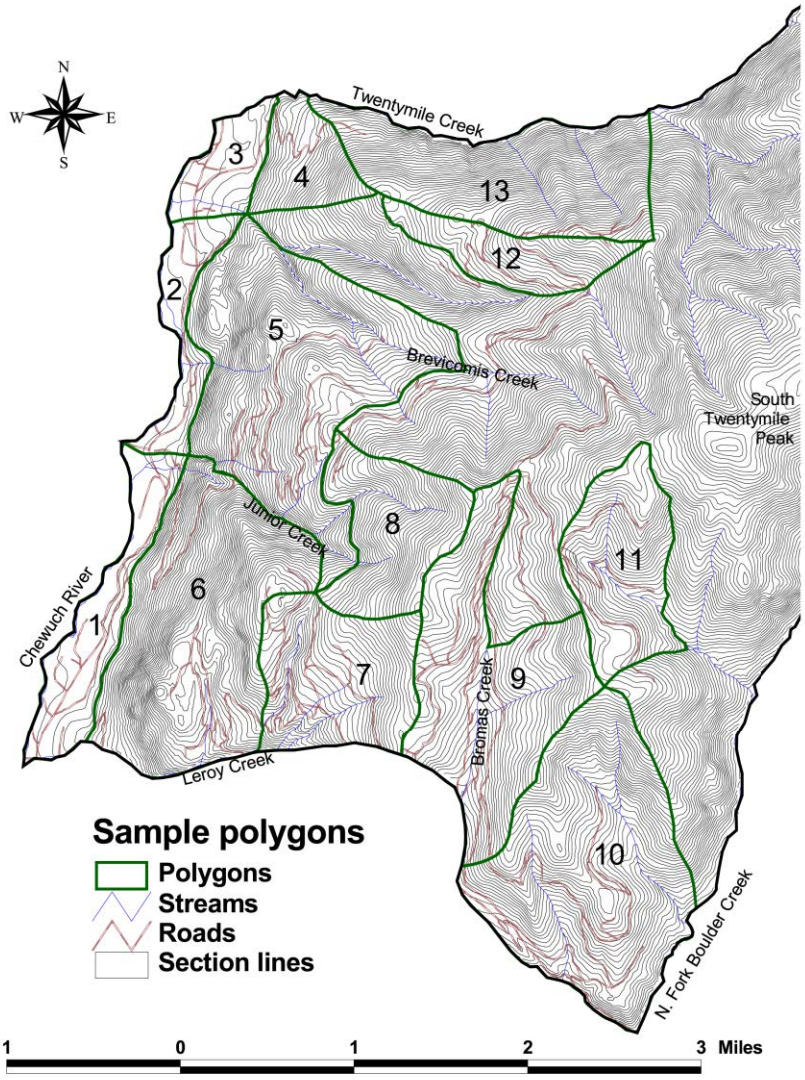
3. METHODOLOGY

3.1 Sampling Design

Previous studies have subdivided landscapes into homogeneous landtypes to assist the fire-history description and reduce statistical variability (Everett et al. 2000, Schellhaas et al. 2000a & 2000b). Polygon boundaries at Twentymile are generally based on topographic features that maximize landscape homogeneity and the probability of a common historical fire

disturbance across the area. This stratification also assisted in the analysis by subdividing this large area into smaller organizational units that are better suited to management objectives. The area was divided into thirteen analysis polygons that ranged in size from 178 to 1,144 acres with a mean size of 568 acres (Figure 2).

Figure 2. Map of Twentymile Planning Area's sampled polygons.

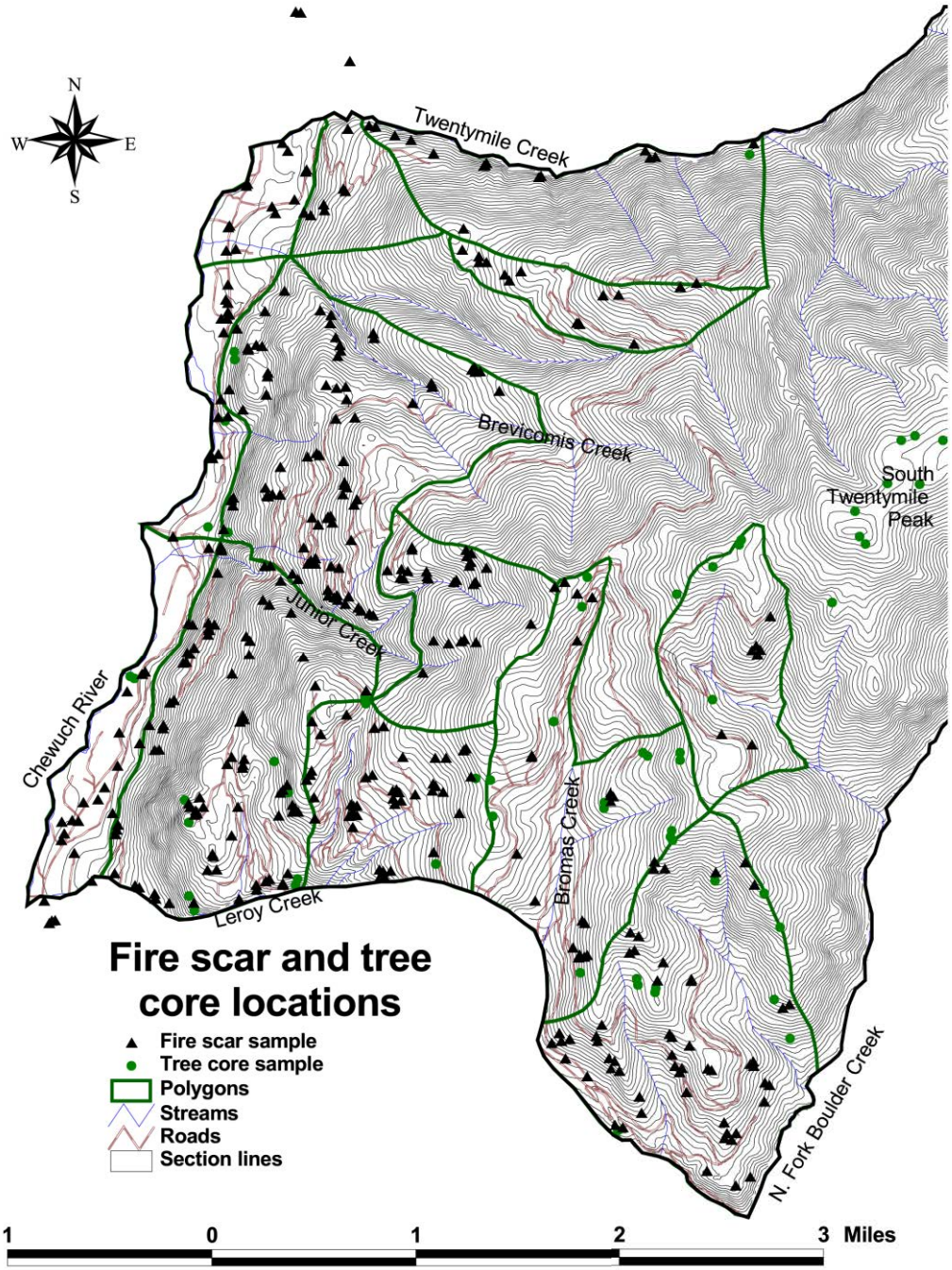


Portions of the Twentymile area were not sampled for various reasons. First of all, where mixed and high-severity fire-regimes are found (generally above 4,500 ft in the Twentymile area), limited evidence resultant of stand-replacement fires is found, providing less accurate fire-history results (Schellhaas et al. 2002). In these forest types, an effort was made to concentrate on areas where a more efficient and accurate assessment could be accomplished in the allotted time frame. This data may then be applied to represent the more remote portions of these habitats. In addition, some areas were considered unsafe for sampling, which included steep, rocky slopes or cliffs. Lastly, results from an earlier report (Schellhaas et al. 2001) were incorporated with our data eliminating the need to revisit the subalpine portions of the Twentymile area.

3.2 Field Methods for Master Chronology and Fire History

Data for this fire history were collected during the summer and fall of 2001 and 2002 within the Twentymile Planning Area. The sampled polygons were intensively searched for evidence of past fires from fire-scarred trees, snags, logs, and cut-stumps in all stand types. Wedges containing fire scars were extracted from live trees and snags using the methods described by Arno and Sneck (1977). Samples from logs and stumps were sectioned to ensure collection of the maximum number of fire-scar events. Whenever possible, multiple samples in close proximity were collected to develop point fire-frequency

Figure 3. Locations of fire-scar and tree-core samples.



intervals. Locations of fire-scarred samples were geo-referenced and entered into a (GIS) database for subsequent mapping of fire locations and fire extent.

Where direct evidence of past fires was scarce, remnant live-trees (those remaining following a fire) and early seral tree species were located and increment cores obtained to infer and extend the fire history record through cohort analysis (sensu Heinselman 1973, Oliver and Larson 1996). In all, 409 fire-scarred samples with an additional 61 increment cores were collected (Figure 3). Of these 61 cores, 14 were from climatically sensitive trees chosen to develop a master chronology to aid in cross-dating. Cross-dating is the process of matching variations in tree-ring widths or other ring characteristics among several samples, allowing the precise year of each ring to be determined (Kaennel and Schweingruber 1995).

In addition to fire-scar samples and tree cores we investigated fire atlases and historical fire databases to document all 20th-century fires at Twentymile that may have been smaller than our fire-scar resolution. This information allows us to also confirm the occurrence of fire since the establishment of the Forest Service.

3.3 Laboratory Preparation and Analysis

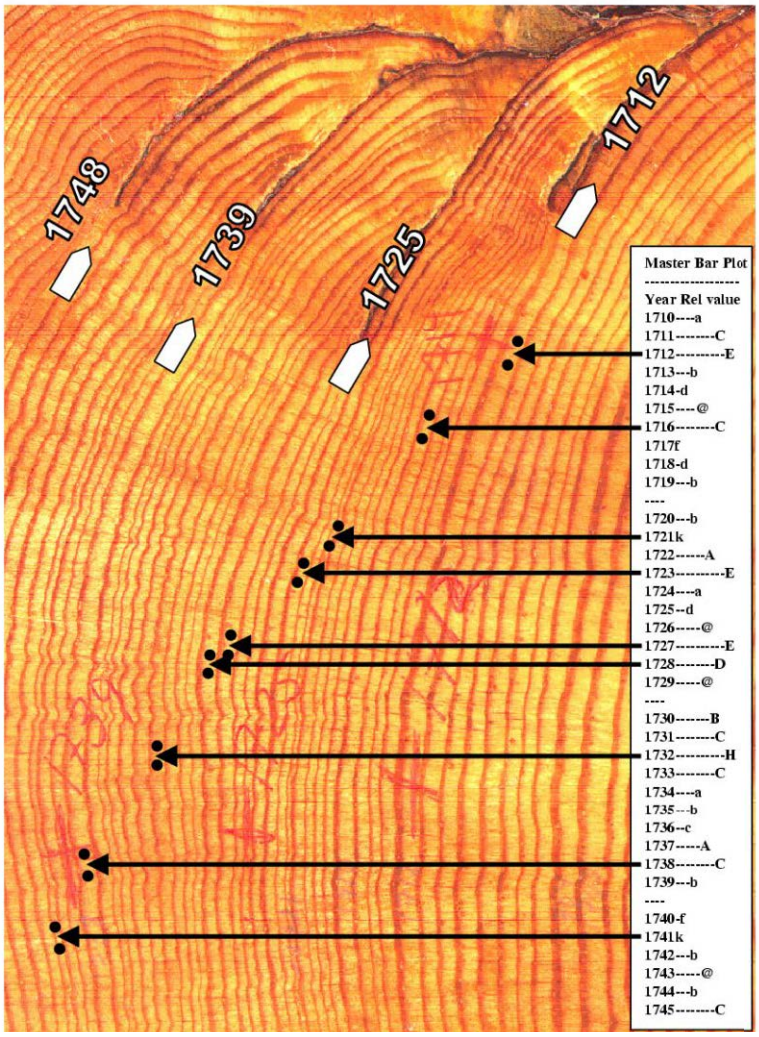


Figure 4. Part of the output of the computer program COFECHA is a "Master Bar Plot" of relative tree-ring widths (a segment is shown above). The bars show the relative width of each year's ring with the longer the bar, the wider the ring. Lower-cased letters signify rings narrower than the local mean while upper-cased letters represent rings wider than average. Note how the wide and narrow rings shown on the bar plot match ring patterns on the fire-scar sample (black arrows) enabling precise fire years to be established (white arrows) [from Schellhaas et al. 2002].

Determining the exact year of a fire through cross-dating is contingent on the development of an accurate master tree-ring chronology, or sequence of tree-ring widths by year that maximizes the local climate signal (Stokes and Smiley 1968, Fritts 1976). Tree growth on dry, well-drained slopes and ridges in the Twentymile area is primarily limited by available soil moisture, which changes in response to annual precipitation. The 14 cores used to develop

the tree-ring chronology are from moisture sensitive trees growing on these harsher sites and have well-defined, narrow growth rings in dry years and distinct wide rings in wet years.

Building the master chronology involved measuring each ring from the 14 climatically sensitive tree-cores on a Velmex sliding-stage micrometer with Acu-Rite encoder using MeasureJ2X software (2001). The tree-ring measurements were then validated for dating accuracy with the COFECHA software program (Holmes et al. 1986) that also produced a graphical master chronology of tree-ring widths representing wet and dry years (Figure 4) analogous to the skeleton plot described by Stokes and Smiley (1968). The inter-correlation (0.56) between the measured tree cores provided a suitable master tree-ring chronology. This chronology included the period from 1528 to 2000 where signature years and recognizable patterns of years were used to cross-date fire scars on each sample and assign the correct calendar year to each scar (Figure 4) (Madany et al 1982, Dietrich and Swetnam 1984, Brown and Swetnam 1994, Grissino-Mayer 1995a). The years that had the most prominent wide and narrow rings became marker years (Yamaguchi 1991) that were used for efficient dating of fire scar samples.

Each fire-scar cross-section was sanded with a progression of sandpapers, concluding with either 320 or 400 grit to allow reading of extremely small growth rings. Some of the sections cut from snags and logs were partly

decomposed and required substantial reassembly before they could be sanded and their fire scars dated. Fire scars from live trees and dead wood were dated by using the list of marker years and by visually comparing ring patterns with those in the master chronology.

Once each fire scar was assigned a date, these data were analyzed using the FHX2 software package (Grissino-Mayer 1995b). The MFFI and WMFFI were computed utilizing the polygon area and point-frequency methods. In addition to the WMFFI determined for each polygon, the Weibull Exceedance Probability was calculated at (α = 0.125) to document any statistically-significant short or long intervals that may be present (Grissino-Mayer 1995b). Grissino-Mayer recommends the less stringent 0.125 statistical-level instead of the usual 0.05-level when making ecological interpretations based on fire-history data. Fire chronologies were assembled for each polygon and for the entire planning area. We sorted point-sample locations by aspect, slope class, 500-foot elevation class, and topographic position for separate analysis to ascertain if these topographic attributes had any bearing on fire frequency. Point and polygon fire-frequency were compared with “t” tests of difference using the 0.05 level of significance (Little and Hills 1978).

Severity and intensity of fire can be inferred by the abundance of fire-scarred trees (Agee 1993) particularly those enduring multiple fires. In addition, a measure of tree diameter when scarring first occurs strengthens conclusions of

fire magnitude (Wright 1996, Everett et al. 2000, Schellhaas et al. 2000a, 2000b & 2002, Gray et al. 2002). When piths from fire-scar samples were present and the first scar had not been damaged by succeeding fires, we measured the diameter of the tree when this initial scar occurred to the nearest 0.1-inch and recorded its age.

Spatial distribution of each fire is displayed through a set of fire extent maps generated from geo-referenced locations of fire-scarred cross-sections (Agee et al. 1986). Fire perimeters are shown on the individual fire year maps in the appendix. In addition to direct fire-scar evidence, we utilized tree core and fire-scar samples exhibiting aberrant ring-patterns that correlated with established fire years. These data further reinforced the established perimeter of fire extents when located within the fire boundary. When this indirect evidence was located outside but adjacent to established fire perimeters, we estimated extensions of fires (shown on the fire extent maps in the appendix). These extensions are for areas likely to have burned, but evidence of this is less certain than for areas based solely on actual scars from fire-scarred samples. Reported fire sizes reflect the more conservative direct-scar estimate and do not include any acreage outside sampled polygons.

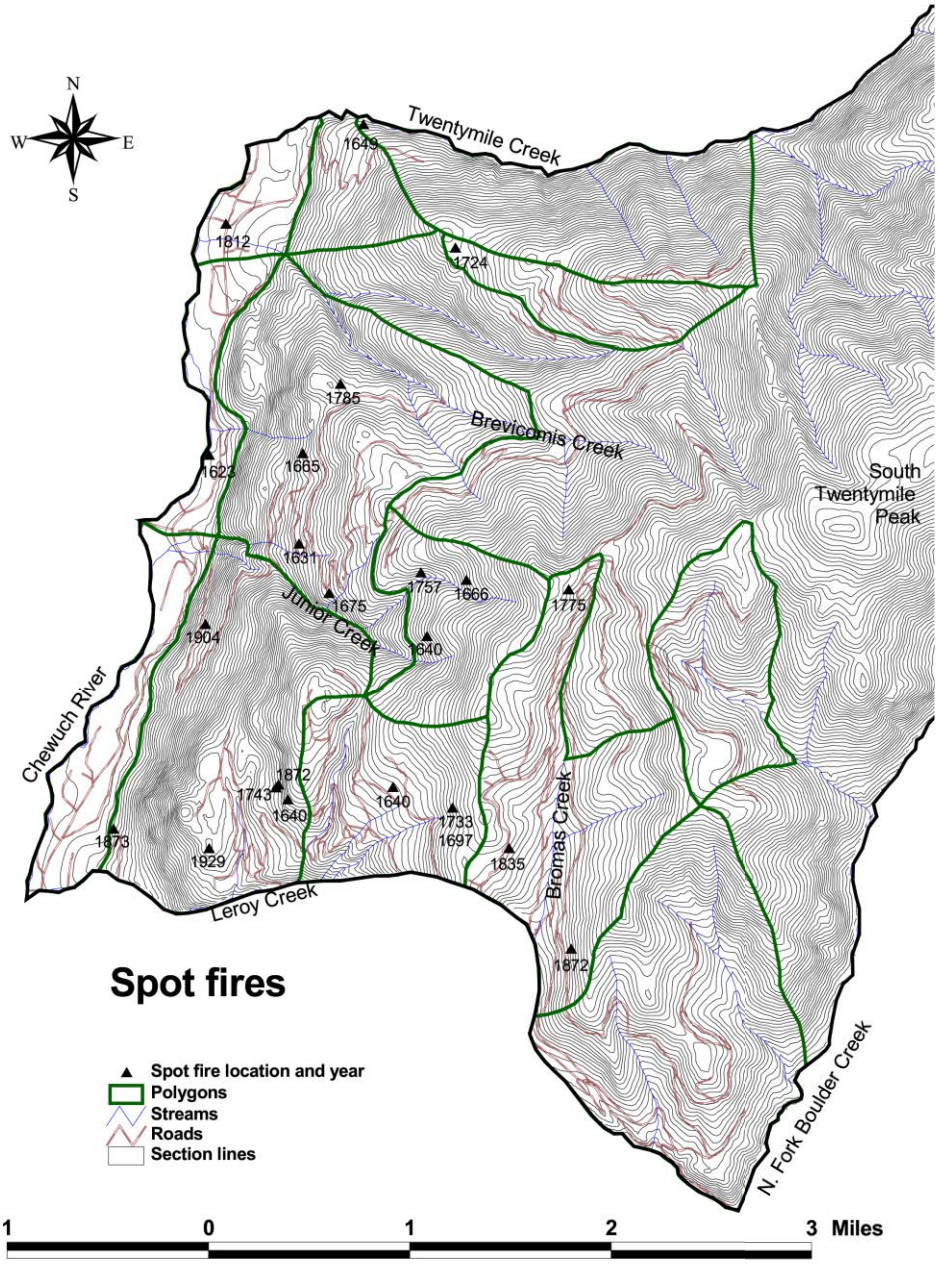
Fire boundaries were developed from criteria similar to those used by Hemstrom and Franklin (1982) where we made the following assumptions:

1. A fire burning within the general area of where the samples were collected would spread until encountering a topographic or fuel barrier.
2. Fire spread was in an uphill direction.
3. Fire boundaries were conservatively estimated; perimeters were not extended beyond the evidence of fire scar or cohort data except by rules 1 and 2.

3.4 Spot Fires

Some ignitions may yield insignificant fires that scar only one tree that we refer to as spot fires. We believe that including spot fires in fire frequency calculations disproportionately affect area fire frequency since resultant ecological impacts are negligible. With this rationale in mind, we have chosen to exclude spot fires from fire frequency analysis at all levels (i.e. planning area, polygon, and points). Spot fires do not appear on fire extent maps and are not included in area-burned summaries. Additionally, single fire-scars that were spatially isolated from a larger fire-perimeter were also excluded from frequency and extent calculations. The distribution of spot fires and the year in which they occurred are reported in Figure 5. It should be noted that probably not all spot fires were discovered. At an average resolution of one scar sample per eighteen acres within sampled polygons, some spot fires were most likely undetected. It is not our intention to resolve the frequency of spot fires, but rather to report their presence when detected.

Figure 5. Spot fire locations and the year of occurrence.



4. RESULTS AND DISCUSSION

4.1 Time Periods

All analysis was based on data from fire-scar samples. A total of 82 individual fires were cross-dated from the 409 scar samples that were collected. The oldest sample collected had a pith dated to A.D. 1149. The earliest fire determined within the Twentymile Planning Area occurred in the year 1342. Fires were also documented occurring throughout the fifteenth and sixteenth centuries. The exceptionally large number and quality of fire-scar samples collected, enabled us to reconstruct the fire history of the sampled portion of the Twentymile Planning Area back to the year 1660. This date is the beginning of the "period of reliability" when each polygon contained at least three sample recorder-trees (trees scarred by fire) (Touchan et al. 1996). Standardizing the period of reliability for each polygon allows direct, unbiased comparisons among polygons. Although we were able to document some very old fire events, the number of surviving fire-scar samples from the 14th, 15th, and 16th centuries was too small to infer fire frequency or size with the same degree of accuracy as the post-1660 period.

Finch (1983) notes that the area surrounding Twentymile was part of the Moses Indian Reservation which was closed to Eurosettlement until it was dissolved in 1886. Impacts of settlement on fire regimes beginning in the late 1800s ("settlement era") that have been observed in other fire history studies in eastern Washington (Everett el al. 2000, Schellhaas et al. 2000a & 2000b) was not apparent in the Twentymile area so we chose not to separate this period. Consequently, our analysis of fire history is divided into only two time periods: 1660-1889 and 1890-2002. We refer to these time periods as the "pre-suppression" and "suppression" eras, respectively. The 1889 cutoff date was chosen as it was observed through fire history analysis that an abrupt change in fire frequency (Figure 6) occurred following that year.

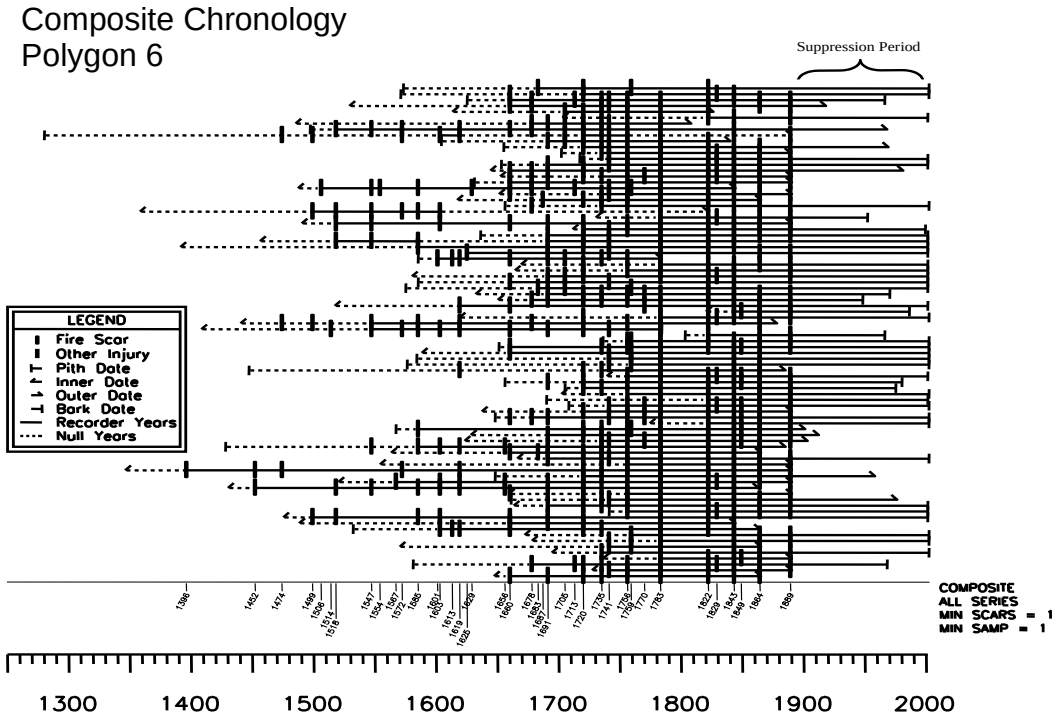


Figure 6. Example composite chronology of fire history generated by FHX2 software (Grissino-Mayer 1995b). Eighty-four fire-scar samples are represented by horizontal lines with short vertical bars marking fire years. An obvious break in the pattern of fire occurrence takes place in Polygon 6 after 1889.

At Twentymile, a dramatic decrease in fire occurrence was exhibited with only two fires reported following 1889. These two fires were small, occurring in 1914 (11 acres in Polygon 6) and 1973 (112 acres total, 15 acres in Polygon 9). They were found in local fire atlases (George 1996) but were not recorded on any of our samples. These fires were not included in frequency analysis, thus aiding standardized comparisons between suppression and pre-suppression time periods by basing all analysis on fire scars and tree cores. The reduced incidence of fire at the end of the 19th Century has also been documented across the western United States and likely results from a combination of factors including livestock grazing, timber harvest, and active fire suppression that significantly altered inherent fire-regimes (Agee 1993, Arno 1988, Arno et al. 1997, Barrett 1988, Everett et al. 2000, Grissino-Mayer and Swetnam 1995, Parsons and DeBenedetti 1979, Schellhaas et al. 2000a & 2000b, Wright 1996).

4.2 Fire-Free Intervals

The following discussions are limited to using only the WMFFI metric. Table 1 displays point WMFFI, area WMFFI with range and exceedance probabilities, and area MFFI for the pre-suppression period. Although we have not used the MFFI for statistical purposes in this report, it is commonly used and is included in Table 1 to allow comparisons with other investigations.

4.2.1 Area Frequency

The pre-suppression WMFFI for the entire sampled portion of the Twentymile area was 5.17 years. As previously described, these numbers reflect that on average, there was a fire somewhere within the sampled area every 5 to 6 years. During the suppression era the overall MFFI was 113 years. Because no fires were recorded on scar samples following 1889, the 2002 collection-year is used as the terminal date for determining suppression era MFFI. It should be understood that this number will actually increase until a significant fire event occurs, resulting in a definite fire-free interval. The interval should then be considered a conservative estimate.

Although it is interesting to know that fires burned somewhere within the planning area every 5 to 6 years during the pre-suppression era, knowledge of the frequency of disturbance across smaller areas is more useful from a management perspective. Accordingly, we reconstructed the fire histories for each of the thirteen polygons (Table 1). The mean pre-suppression WMFFI for Polygons 1 through 13 was 16.1 and ranged from 9.5 years in Polygon 5 (low-severity fire-regime) to 43.4 years in Polygon 11 (mixed-severity fire-regime). Statistically, area WMFFI for Polygon 8 is significantly longer ($\alpha = 0.05$) than all polygons except Polygons 9 through 12. WMFFI for Polygon 9 is significantly longer ($\alpha = 0.05$) than Polygons 2, 3, 5, and 6. Finally, WMFFI for Polygon 11 is

significantly longer (α = 0.05) than all other polygons except Polygons 9 and 10 (Table 1).

Table 1. Fire frequency summary for polygons within Twentymile Planning Area.

Polygon #	1660 - 1889				
	Point WMFFI	**Area WMFFI**	**Area Range**	**Area MFFI**	**Weibull Exceedance Probability Range**
1	18.63	11.62	2-39	13.5	4-25
2	18.14	13.37	3-45	15.3	4-28
3	14.4	10.12	3-45	12.0	3-23
4	17.82	11.96	3-45	14.3	4-27
5	25.09	9.5	1-45	12.0	2-24
6	23.27	10.68	3-39	12.0	4-22
7	24.34	15.1	4-39	16.4	6-28
8	24.27	21.2**a**	15-25	20.8	17-24
9	33.36	19.09**b**	3-46	20.8	8-35
10	35.22	16.62	2-80	22.9	4-47
11	59.05	43.36**c**	18-84	45.7	19-74
12	28.91	13.38	1-45	17.6	3-35
13	28.19	13.06	1-27	14.3	5-24
Mean	26.98	16.08	1-84	18.12	2-74
SD	11.42	8.89		8.93	
CV	0.423	0.553		0.493	
Entire area	**25.66**	**5.17**	**1 – 17**	**5.72**	

a – *Weibull median FFI for polygon 8 is significantly longer than polygons 1 through 7 and 13.*
b - *Weibull median FFI for polygon 9 is significantly longer than polygons 2,3,5 and 6.*
c - *Weibull median FFI for polygon 11 is significantly longer than all other polygons except 9 and 10.*

(0.05 level of significance)

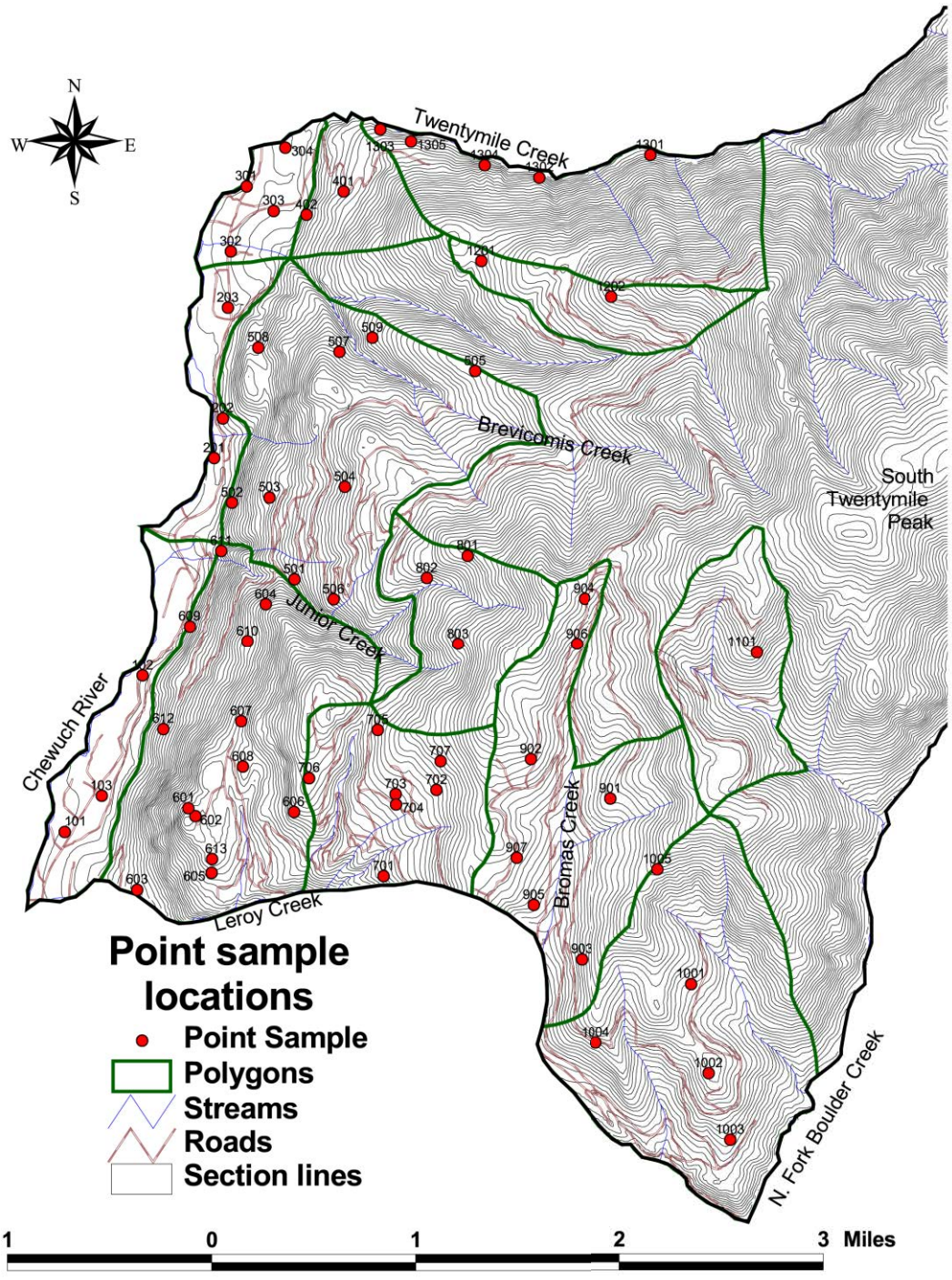
4.2.2 Point Frequency

Figure 7 displays the 64 locations for which point-based estimates of WMFFI are derived. The point-based estimates were generally longer than the area-based estimates, ranging from 11.9 to 59.0 years with a grand mean of 25.7 years and coefficient of variation of 0.34. Variation at individual points was more pronounced at points than at polygons. Intervals at points ranged from 3 to 102 years whereas polygons varied from 1 to 84 years (Table 2 in appendix).

Generally, point fire-frequency was variable across all topographic attributes. Mean WMFFI ranged from 22.2 to 33.7 years by aspect, 18.8 to 28.5 by slope class, 16.5 to 30.7 by topographic position, and 21.2 to 31.9 by elevation class for individual points (Figure 8 in appendix). West aspects were statistically shorter than east or south. Flat slopes are significantly shorter than moderate or steep ones. Valley bottoms are significantly shorter than middle-thirds and upper-thirds. Elevation class 8 (5,500' – 6,000') is statistically longer than all other classes. Class 2 (2,500' – 3,000') is statistically shorter than 6 and 7(4,500' – 5,500'), and 1 (2,000' – 2,500') is statistically shorter than 5, 6, and 7(4,000' – 5,500').

The WMFFIs in the Twentymile Planning Area are influenced by elevational gradients, lengthening with increases in elevation. WMFFI for the polygons lowest in elevation (1, 2 and 3) (<2,400') average 11.7 years. Polygons

Figure 7. Point sample locations.



4, 5, 6 and 13 (mean elevation = 3,500') average 11.3 years. When the mean elevation rises between 4,500 to 5,500 feet, the frequency increases substaintially to 17.1 years. Finally, the frequency for elevations greater than 5,500 feet average 43.4 years. Perhaps a better illustration of the elevation and frequency relationship can be observed by examining the point samples, most notably the elevation attribute. The fire frequency lengthens steadily as elevation increases by 500-foot increments. Topographic position also exhibits the relative influence of elevation to frequency. The valley bottom attribute displays a mean interval of 16.5 years, much shorter than those positions higher on the slope (24.7- 34.7 years). It should be noted that flat slopes, which express the shortest fire frequencies, are primarily at low elevations located along the flood plain of the Chewuch River.

4.3 Fire Extent

The estimated number of acres burned within the sampled portion of the area each year since 1660 is shown in Figure 9. The average percent a polygon burned in a single fire event ranged from 33% in Polygon 13 to 72% in Polygon 4 (Table 3). Mean fire size within Polygons 1 through 13 was 1,502 acres, with a range of 19 to 6,749 acres.

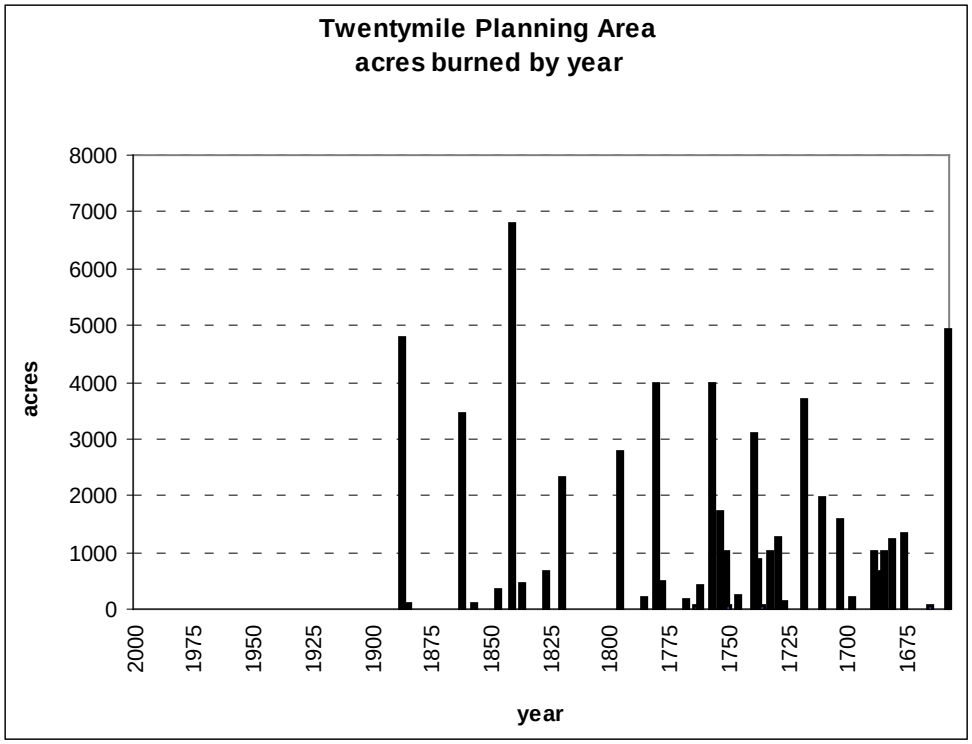


Figure 9. Fire size (acres) by year for the Twentymile Planning Area from 1660 to present.

Table 3. Summary of fire size (acres) within the polygon and mean percentage of polygon burned for the Twentymile Planning Area.

	1660 - 1889				
Polygon	Total Acres	Mean Acres Burned	CV	Range	% Burned
1	342	209	0.55	16 - 342	61
2	208	103	0.76	3 - 208	50
3	178	118	0.48	9 - 178	66
4	211	152	0.37	64 - 211	72
5	1,144	553	0.74	3 – 1,144	48
6	1,035	557	0.67	4 – 1,035	54
7	513	362	0.54	33 - 513	71
8	411	274	0.52	30 - 411	67
9	846	331	0.76	82 -846	39
10	1,096	489	0.88	7 – 1,096	45
11	435	208	0.84	52 - 435	48
12	257	111	0.92	8 - 257	43
13	713	234	0.92	11 - 713	33
Polygons 1 - 13	**7,389**	**1,502**	**1.12**	**19 - 6,749**	**22**

The series of maps in the Appendix display locations and estimated sizes of fires for each of the years in which we documented fire activity within the Twentymile Planning Area. Because fire sizes were conservatively estimated and include only the portion of the Twentymile area within the thirteen sampled polygons, the actual fire sizes were likely to have been somewhat larger than estimated (Table 4 in appendix). Of the 38-recorded fires during the pre-suppression era, 11 of these were considered large fires (sensu Everett et al. 2000) (burning a minimum of 25% of the total sampled area on average every 22.9 years).

To quantify differences between polygons, we computed Jaccard Similarity Indices (JSI) between pairs of polygons (Table 5). A higher Jaccard Similarity Index indicates that the polygons being compared shared more common fire events and thus the topography between polygons was not as effective in stopping spread of fire.

We cannot draw many conclusions about similarity between opposing and adjacent ridges or drainages because most polygons are generally not separated by substantial ridges or draw bottoms. However, fires did burn across some ridges and draw bottoms within polygons suggesting these topographic features may not always serve as effective fuelbreaks. Relationships between sideslope

Table 5. Fire year synchroneity (Jaccard Index) between polygons within the Twentymile Planning Area (1660-1889).

Polygons	% Similarity	Polygons	% Similarity	Polygons	% Similarity
1-2*	31	3-7	30	6-9	52
1-3	31	3-8	33	6-10	29
1-4	30	3-9	28	6-11	25
1-5	36	3-10	15	6-12	36
1-6*	73	3-11	14	6-13	48
1-7	57	3-12	42	7-8*	59
1-8	43	3-13	48	7-9*	69
1-9	43	4-5	61	7-10	37
1-10	21	4-6	37	7-11	25
1-11	21	4-7	28	7-12	31
1-12	28	4-8	38	7-13	38
1-13	35	4-9	32	8-9*	50
2-3*	71	4-10	17	8-10	31
2-4	65	4-11	16	8-11	36
2-5*	71	4-12	48	8-12	50
2-6	38	4-13*	54	8-13	58
2-7	29	5-6*	54	9-10*	44
2-8	40	5-7	46	9-11*	38
2-9	27	5-8*	52	9-12	27
2-10	17	5-9	39	9-13	36
2-11	17	5-10	29	10-11	25
2-12	43	5-11	25	10-12	18
2-13	50	5-12	54	10-13	27
3-4*	85	5-13	61	11-12	38
3-5	60	6-7*	67	11-13	20
3-6	38	6-8	52	12-13*	67

**Adjacent polygons*

and upslope connectivity is represented in JSI between Polygons 1, 2, 5, and 6 (Table 5). These polygons are well connected and provide a good comparison with directional correlations. Sideslope association between Polygons 1 and 2 was 31% and was 54% between Polygons 5 and 6. There is much greater

linkage upslope as seen in the JSIs from Polygons 1 and 6 (73%) and Polygons 2 and 5 (71%). These JSIs suggest that fires lower on a slope are more likely to spread in upslope fashion than across slope (Pyne 1984). They appear to do this in spite of prevailing down-valley afternoon winds (Agee 1994). Large spatial separation results in lower similarity indices as exhibited by 3-10, 3-11, 2-10, 2-11, 4-10, and 4-11 paired polygon comparisons (Table 5).

4.4 Areas of Mixed Severity

Some areas of mixed severity were not extensively sampled in this study but were mapped and found in the transitional areas between the lower-elevation frequent fire-regime and high-elevation subalpine forests (Schellhaas et al. 2001). Portions of Polygon 8, 9, and 11 are within this type of regime. Stand-type delineation, developed from aerial photos, depicts a patchy network of single-layer stands typical of more destructive fire effects. When these areas were reconnoitered, field conditions associated with mixed-severity regimes were observed and noted in some portions of the polygons. A general lack of fire scar evidence was conspicuous and single-layer lodgepole stands often linked to mixed or high-severity regimes were present. The WMFFIs calculated for these polygons were in the 20-40 year range with maximum intervals of 80 or more years. These longer fire-free intervals promote fuel accumulation and overstory and/or understory stand development that allow subsequent fires to burn at higher intensities that lead to stand replacement (Agee 1994).

4.5 Native American Burning

Some researchers (Everett et al. (2000) and Barrett and Arno (1982)) have found increased fire frequencies near major valleys and speculate this may be the result of Native American activities. Finch (1983) studied forests near Twentymile and reported that native burning was documented in the vicinity "to promote the growth of plants for human and wildlife use and to make travel through the areas easier." Although it is likely that some of the fires reported were the result of native ignitions, historical lightning-caused and anthropogenic ignitions are practically impossible to distinguish and are beyond the scope of this study.

5. SUMMARY

Three types of fire regime occur at Twentymile: low, mixed, and high-severity regimes (Figure 1). Approximately 30% of the area is considered within a low-severity fire-regime and generally occur at elevations below 4,500 feet. Polygons 1-7, 10, 12, and 13 primarily exhibit frequencies typical of this type of regime. Polygons 8, 9, and 11 have longer frequencies and aerial photography yields evidence of small stand-replacement burns in these polygons, typical of mixed-severity fire-regimes. Field reconnaissance also confirmed the presence of stands resulting from replacement burns. The 1843 fire that burned the

majority of the 13 sampled polygons had apparently spread to the subalpine zone (high-severity fire-regime), resulting in a stand-replacement burn there. Although Schellhaas et al. (2001) reports that this fire occurred in 1841, we believe 1843 is the correct year because of more precise direct scar cross-dating techniques used in this report. Age-class distribution procedures (sensu Heinselman 1973) used by Schellhaas et al. (2001) are less precise although yield useful results in the absence of more reliable fire-scar information.

Elevation plays an important role in fire frequency in the Twentymile area. In general, as elevation increases, fire frequency lengthens. We show that elevation is a factor affecting frequency in the Twentymile area and that there is connectivity of disturbance between low elevation and high elevation forests. As stated, we have determined that at least two fires (1841 and 1889) reported by Schellhaas et al. (2001) in the subalpine portion of the Twentymile area have common fire dates with this report.

Results from this study indicate that the inherent fire-regime for a portion of the Twentymile Planning Area (Polygons 1 - 7, 10, 12, and 13) was primarily one of high frequency, low-severity fires. This low severity is demonstrated by the fact that the mean diameter of trees at stump height when first scarred was 4.2 inches with a range of 0.5 to 14 inches. Moreover, this is also shown by the abundance of fire-scared trees surviving multiple burns. This fire regime is typical of the dry forest types in the ponderosa pine, Douglas-fir, and grand fir series

along the eastern slopes of the Washington Cascade mountains (Everett et al. 2000).

The pre-suppression area WMFFI range of 9.5 to 16.6 for polygons 1-7, 10, 12, and 13 is within the range of what is considered a frequent, low-severity fire-regime (Agee 1999). Fire effects on forest structure would vary little between these upper and lower parameters except for the shrub layer. Longer intervals may allow this layer to advance further between successive fire events while shorter intervals would likely only maintain a grass component (Agee 1994 and Agee 1999). Overstory stand structure would not deviate greatly within this range of frequency and would consist of a uniform mosaic of mature-tree clusters (Agee 1999). The range of 19.1 to 43.4 found in Polygons 8, 9, and 11 is within the range of the mixed-severity fire-regime (Arno 1976, Barrett et al. 1991, Agee 1994, Schellhaas et al. 2000a and 2002).

Short fire frequencies suggest that low-elevation forests at Twentymile were historically dominated by species more tolerant of fire such as ponderosa pine and Douglas-fir, since even low-severity fires would kill trees that were more sensitive to fire. Unlike findings reported by Schellhaas et al. (2002) which had short fire intervals (5 – 11 years on average), forests in the low-severity regime at Twentymile on average experienced fire every 9 – 16 years (Polygons 1-7, 10, 12, and 13) (Table 1). Douglas-fir would have been a major component of these pre-suppression forests and even though it is quite intolerant of fire when very

young (Arno 1988, p. 133), the longer intervals at Twentymile mitigate this characteristic of juvenile Douglas-fir. Longer fire-free intervals could have allowed more shade tolerant species to establish and grow tall enough to create a fuel ladder to the overstory. Subsequent fires might then have become stand replacing in those areas (sensu Everett et. al. 2000).

Polygons at Twentymile are currently out of synchrony with historical WMFFIs on average by a factor of nine in the low-severity areas (Polygons 1 - 7, 10, 12, and 13). Mixed-severity polygons, on average, are out of agreement by four fire-free intervals, and even landscapes in high-severity areas are two to three times beyond the historical average. Currently, most vegetation is connected horizontally and vertically across the landscape, predisposing this area for fires that are of greater severity than those that occurred during the past several centuries. This is especially true for areas with historically low and mixed-severity fire-regimes. While high-severity regimes may not be beyond historical conditions for individual stands, landscapes today appear to be more homogonous (Schellhaas et al. 2001) and at Twentymile have diverged two to three times from the historical average. Historically, diversity in the subalpine landscape may have provided fuel barriers to retard the expansion of fire under certain conditions.

6. MANAGEMENT IMPLICATIONS

This paper summarizes that the fire-disturbance regime for the Twentymile area has diverged from historical conditions. To mitigate risks from catastrophic fire, an alternative is to configure stand structure and species composition to sustainable conditions based on historical regimes. Maintenance of historical disturbance patterns and processes could then become the emphasis, which would entail reduced connectivity in surface fuels or understory vegetation in low-severity areas and patchiness of overstory in mixed-severity areas.

Data for mixed-severity areas is somewhat limited but reveal opportunities for a different array of management options. Overstory patchiness was more apparent in the mixed-severity fire-regime and fragmentation in the overstory detected historically implies periodic openings in canopy cover, which have many ecological benefits. For example, openings are important for some species of wildlife and the successful establishment of shade-intolerant plant species. It should be recognized however, that some areas likely experienced a gradient in lethality where single trees or small groups were left within a matrix of stand regeneration.

An aid for managing the low and mixed-severity areas can be found in the range of variability around WMFFI and MFFI intervals. It allows managers the

flexibility needed to cope with the range of workforce, fiscal, or environmental concerns. The area range listed in Table 1 displays the actual maximum and minimum intervals recorded. A better tool would be the Weibull Exceedance Probability range, also found in Table 1, which only lists values within a certain significance level as related to the Weibull median, thus eliminating the statistically long and short intervals. The Weibull Exceedance Probability prioritizes the temporal distribution and allows the land manager to focus on the most significant portion of this range. For example, Polygon 5 has a range of actual fire-free intervals from 1 to 45 years whereas the Weibull Exceedance Probability range for this polygon is 2 to 24 years. This supports the conclusion that managing in 2 to 24 year intervals is more statistically valid than in 1 to 45 year intervals.

Historical disturbance patterns can guide land managers in the design of treatments and patch sizes across the landscape. The fire extent maps in the appendix illustrate a mosaic of burn patterns across the landscape demonstrated by the fires in 1678, 1683, 1687, and 1689. It is interesting to note that the 1740 fire in the vicinity of Brevicomis Creek provided a fuel break to the fire in 1741. The same is true for the 1756 fire which acted as a fuel break for the 1759 fire in the southwest area indicating a reduced likelihood to re-burn areas recently burned. This situation is generally observed in low-severity fire-regimes within three to four years after fire until grass and litter amounts are replenished. Agee

(1999) also reports that previous fires form natural barriers and are effective in limiting the spread of subsequent fires for up to three years.

Use of the means, medians, and ranges of historical fire-frequency and size could be used as a guide for management within the Twentymile Planning Area. These historical disturbance patterns can help design a spatial and temporal mosaic pattern of treatments and patch sizes across the planning area to help fragment fuel continuity and ensure the sustainability of these forests.

CITED REFERENCES

Agee, James K. Professor and Chair, Division of Ecosystem Science and Conservation, College of Forest Resources, University of Washington, Seattle, Washington.

Agee, J.K., 1993. Fire Ecology of Pacific Northwest Forests. Island Press, Washington, D.C.

Agee, J.K., 1994. Fire and weather disturbances in terrestrial ecosystems of the eastern Cascades. Gen. Tech. Rep. PNW-GTR-320. Portland, OR: US Dept. of Agriculture, Forest Service, Pacific Northwest Research Station. 52p.

Agee, J.K., 1999. Fire effects on landscape fragmentation in Interior West forests. p. 43-60. In: Forest fragmentation-wildlife and management implications. Koninklijke Brill NV, Leiden, The Netherlands.

Agee, J.K., Finney, M., deGouvenain, R., 1986. The fire history of Desolation Peak, Washington. USDI National Park Service Final Report CA-9000-3-0004. National Park Service Cooperative Park Studies Unit, College of Forest Resources, University of Washington, Seattle.

Arno, S.F., 1976. The historical role of fire on the Bitterroot National Forest. Res. Pap. INT-187. Ogden, UT: USDA Forest Service, Intermountain Forest and Range Experiment Station. 29 p.

Arno, S.F., 1988. Fire ecology and its management implication in ponderosa pine forests. In: Baumgartner, D., Lotan, J. (Eds.), Proc. Symp. on Ponderosa Pine – the Species and its Management. Washington State University, Pullman.

Arno, S.F, Smith, H.Y., Krebs, M.A., 1997. Old growth ponderosa pine and western larch stand structures: influences of pre-1900 fires and fire exclusion. Res. Pap. INT-RP-495. Ogden, UT: USDA Forest Service, Intermountain Research Station. 20 p.

Arno, S.F., Sneck, K.M., 1977. A method for determining fire history in coniferous forests of the Mountain West. USDA For. Serv. Gen. Tech. Rep. INT-42.

Barrett, S.W., 1988. Fire suppression's effects on forest succession within a central Idaho wilderness. West. J. Appl. For. 3(3): 76-80.

Barrett, S.W., Arno, S.F., 1982. Indian fires as an ecological influence in the Northern Rockies. J. For. 80, 647-651.

Barrett, S.W., Arno, S.F., Key, C.H., 1991. Fire regimes of western larch – lodgepole pine forests in Glacier National Park, Montana. Can. J. For. Res. 21: 1711-1720.

Brown, P.M., Swetnam, T.W., 1994. A cross-dated fire history from coast redwood near Redwod National Park, CA. Can. J. For. Res. 24: 21-31.

Dieterich, J.H., Swetnam, T.W., 1984. Dendrochronology of fire-scarred ponderosa pine. For. Sci. 30: 238-247.

Everett, R.L., Schellhaas, R., Keenum, D., Spurbeck, D., Ohlson P., 2000. Fire history in the ponderosa pine / Douglas-fir forests on the east slope of the Washington Cascades. For. Ecol. and Mgmt.129: 207-225.

Finch, D., 1983. Fire history on selected sites on the Okanogan National Forest. Okanogan NF. Okanogan, WA. 98840-9723. 24 pgs.

Fritts, H.C., 1976. Tree rings and climate. Academic Press, London.

George, Barry. 1996. Database of fire occurrence on the Okanogan National Forest derived from ranger district fire atlases. ("Fireallc").

Gorman, M.W., 1899. Eastern part of the Washington forest reserve. 19th annual report, part V. Washington D.C. U.S. Department of the Interior, Geological survey. pp. 315-350.

Gray, R., Blackwell, B., Iverson, K., Wong, C., MacKenzie, K., 2002. Past fire regimes in the interior Douglas-fir, dry cool subzone, Fraser Variant (IDFdk3). Report to Lignum Ltd., Williams Lake, British Columbia. 258 p.

Grissino-Mayer, H.D., 1995a. Tree-ring reconstructions of climate and fire history at El Malpais National Monument, New Mexico. Ph.D. Dissertation, University of Arizona, Tucson.

Grissino-Mayer, H.D., 1995b. FHX2: Software for the analysis of fire history from tree rings. Laboratory of Tree Ring Research, University of Arizona, Tucson.

Grissino-Mayer, H.D., Swetnam, T.W., 1995. Effects of habitat diversity on fire regimes in El Malpais National Monument, New Mexico. In: Brown, J.K.; Mutch, R.W.; Spoon, C.W.; Wakimoto, R.H. (tech. coords.), Proceedings: symposium on fire in wilderness and park management. 1993 March 30-April 1. Missoula, MT. Gen.Tech. Rep. INT-GTR-320. Ogden, UT: USDA Forest Service, Intermountain Research Station.

Heinselman, M.L., 1973. Fire in the virgin forests of the Boundary Waters Canoe Area, Minnesota. Quat. Res. 3: 329-382.

Hemstrom, M.A., Franklin, J.F., 1982. Fire and other disturbances of the forests in Mount Rainier National Park. Quat. Res. 18: 32-51.

Holmes, R.L., Adams, R.K., Fritts, H.C., 1986. Quality control of crossdating and measuring: a users manual program COFECHA. In: Tree-Ring Chronologies of Western North America: California, eastern Oregon and northern Great Basin. Laboratory of Tree-Ring Research, University of Arizona, Tucson, AZ. pp 41-49.

Kaennel, M., Schweingruber, F.H., 1995. Multilingual Glossary of Dendrochronology. Paul Haupt Publishers, Berne, Switzerland. 467 p.

Keenum, D., (in prep.) Sustainability of northern spotted owl habitat in the *Abies grandis* series of eastern Washington. M.S. Thesis. University of Washington, Seattle.

Kilgore, B.M., Taylor, D., 1979. Fire history of a sequoia-mixed conifer forest. Ecology 60: 129-141.

Little, T.M., Hills, F.J., 1978. Agriculture experimentation: design and analysis. John Wiley and Sons, New York.

Madany, M.H., Swetnam, T.W., West, N.E., 1982. Comparison of two approaches for determining fire dates from tree scars. For. Sci. 28: 856-861.

Measure J2X, 2001. Tree ring measuring program. VoorTech Consulting, Holderness, NH.

Ohlson, T.H., 1996. Fire regimes of the ponderosa pine-Douglas-fir/beardless bluebunch wheatgrass plant association in the Methow Valley of North Central Washington. MS thesis, Pullman, WA: Washington State University. 87 p.

Oliver, C.D., Larson, B.C., 1996. Forest stand dynamics. John Wiley and Sons, Inc. New York.

Parsons, D.J., DeBenedetti, S.H., 1979. Impact of fire suppression on a mixed-conifer forest. For. Ecol. and Mgmt. 2: 21-33.

Pyne, S.J., 1984. Introduction to wildland fire: fire management in the United States. John Wiley and Sons, Inc. New York.

Schellhaas, R., Camp, A.E., Spurbeck, D., Keenum, D., 2000a. Report to the Colville Natiional Forest on the results of the South Deep watershed fire history research.

Schellhaas, R., Spurbeck, D., Ohlson, P., Camp, A.E., Keenum, D., 2000b. Report to the Colville National Forest on the results of the Quartzite planning area fire history research.

Schellhaas, R., Spurbeck, D., Ohlson, P., Keenum, D., Conway, A., 2002. Report to the Okanogan and Wenatchee National Forests on the results of the Frosty Creek Planning Area fire history research.

Schellhaas, R., Spurbeck, D., Ohlson, P., Keenum, D., Riesterer H. 2001. Fire Disturbance Effects in Subalpine Forests of North Central Washington.

Stokes, M.A., Smiley, T.L., 1968. An introduction to tree ring dating. The University of Chicago Press, Chicago, IL.

Touchan, R., Allen, C.D., Swetnam, T.W., 1996. Fire history and climatic patterns in ponderosa pine and mixed-conifer forests of the Jemez Mountains, northern New Mexico. In: Allen, C.D. (tech. ed.). Fire effects in southwestern forests: Proceedings of the second La Mesa fire symposium. 1994 March 29-31. Los Alamos, NM. Gen.Tech. Rep. RM-GTR-286. Fort Collins, CO: USDA Forest Service, Rocky Mountain Forest and Range Experiment Station. 216 p.

Wright, C.S., 1996. Fire history of the Teanaway River drainage, Washington. University of Washington, Seattle. M.S. thesis.

Yamaguchi, D.K., 1991. A simple method for cross-dating increment cores from living trees. Can. J. For. Sci. 21: 414-416.

APPENDIX

Table 2. Point-based estimates of fire frequency for 64 points in the Twentymile Creek area (1660-1889).

Point	WMFFI	SD	Min FI	Max FI	Point	WMFFI	SD	Min FI	Max FI
101	16.36	15.83	6	60	611	28.52	17.21	18	60
102	19.54	11.76	6	42	612	22.34	10.34	6	39
103	19.99	10.07	4	39	613	20.46	10.46	7	39
201	17.56	11.74	5	45	701	20.60	7.55	13	39
202	19.06	11.16	6	45	702	22.56	9.56	8	39
203	17.81	28.56	3	93	703	25.53	7.62	15	39
301	12.71	10.38	3	45	704	28.31	11.06	18	51
302	11.94	12.53	3	45	705	22.80	7.88	11	39
303	17.23	12.80	5	45	706	18.47	8.98	6	39
304	15.72	11.19	5	45	707	32.12	13.78	14	51
401	19.93	16.45	5	53	801	24.86	11.62	15	45
402	15.72	11.19	5	45	802	22.53	9.64	15	45
501	18.57	14.68	4	60	803	25.42	10.57	15	45
502	23.85	14.91	7	60	903	28.62	9.04	21	46
503	17.94	10.76	6	45	904	31.17	18.48	15	63
504	19.86	10.81	6	45	905	30.80	9.65	21	46
505	36.74	13.83	18	53	906	32.21	19.87	18	63
506	20.03	10.08	7	45	907	39.44	37.56	15	102
507	32.53	13.03	19	53	1001	43.98	26.29	28	84
508	17.70	11.22	5	45	1002	33.04	13.23	23	48
509	38.58	12.81	19	53	1003	44.51	21.14	28	80
601	30.70	9.84	21	42	1004	28.30	24.20	4	80
602	24.82	7.21	15	39	1005	26.27	26.79	10	84
603	15.97	10.24	6	39	1101	59.05	35.79	36	102
604	22.50	9.47	6	39	1201	31.52	17.35	15	54
605	25.59	7.06	15	39	1202	26.31	17.70	7	53
606	20.00	10.4	6	39	1301	36.26	15.50	21	60
607	21.60	9.43	7	39	1302	31.71	18.50	15	60
608	20.24	9.54	6	39	1303	28.40	11.22	15	46
609	27.25	17.44	3	57	1304	26.75	16.72	7	53
610	22.52	9.53	6	39	1305	17.81	11.21	6	45

Table 4. Acres burned by year and polygon.

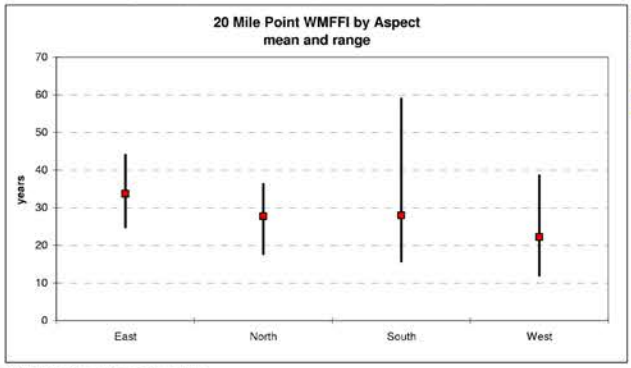
Fireyear	Poly 1	Poly 2	Poly 3	Poly 4	Poly 5	Poly 6	Poly 7	Poly 8	Poly 9	Poly 10	Poly 11	Poly 12	Poly 13	Total
1660	258	3	95	99	776	992	513	81	295	1096	90	184	434	4916
1667			24											24
1678	342	66	16		278	446	149							1297
1683					174	95	193	197	166	371				1196
1687		30	135	136	508	4							169	982
1689										641				641
1691	103					762	126							991
1700			96	72										168
1705					96	88	513	398	222	94	106	10	11	1538
1713	16	92	98	208	1042	148						153	176	1933
1720	248	58	96	113	805	915	512	410	88			13	405	3663
1729												36	74	110
1731									155	1096				1251
1735	249				3	671	66							989
1738		28			15									43
1740		32	178	208	278							8	139	843
1741	103	29			856	601	33	351	422	7	358	209	87	3056
1748			136	64										200
1752												19		19
1753		164	169	198	369							8	75	983
1756	251		9	78		796	490		82					1706
1759	91	208	68	153	1144	279		410	173	1078	52		288	3944
1764		25	169	118	67									379
1766	52													52
1770	82					57								139
1780		79	166	117	79									441
1783	342	208	95	174	883	910	498	107	307			187	234	3945
1788		61	102											163
1798		149	178	211	1006			219				257	713	2733
1822	248					898	513	30	457				131	2277
1829	112					534								646
1839										409				409
1843	342	208	178	211	1144	1035	513	411	846	456	435	257	713	6749
1849	238					95								333
1859													74	74
1864	342	208	178	211	758	919	442	280				15	66	3419
1887										55				55
1889	342	208	178	211	776	904	514	394	762	79		196	187	4751
Total	**3761**	**1856**	**2364**	**2582**	**11057**	**11149**	**5075**	**3288**	**3975**	**5382**	**1041**	**1552**	**3976**	**57058**

Point fire-free interval by aspect

1660-1889

Aspect	minimum	maximum	mean	SD	C of V	n
East	24.82	43.98	33.74	6.85	0.2	6
North	17.7	36.26	27.73	6.77	0.24	8
South	15.72	59.05	27.94	10.82	0.39	19
West	11.94	38.58	22.17	6.1	0.27	31

West is significantly shorter than East (p=.009) and South (p=.047)

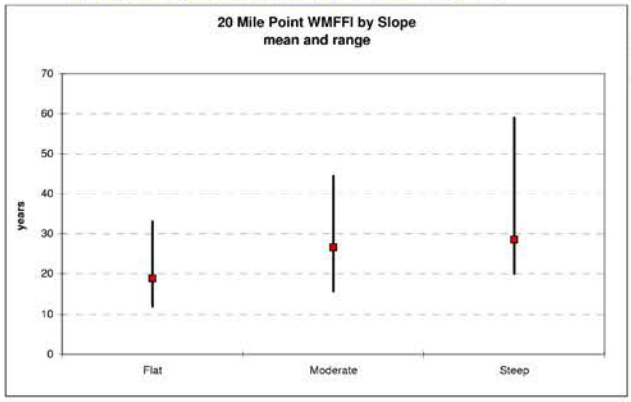


Point fire-free interval by slope

1660-1889

Slope	minimum	maximum	mean	SD	C of V	n
Flat	11.94	33.04	18.82	5.68	0.3	12
Moderate	15.72	44.51	26.62	8.09	0.3	35
Steep	20	59.05	28.52	9.25	0.32	17

Flat is significantly shorter than Moderate (p=.014) and Steep (p=.006)

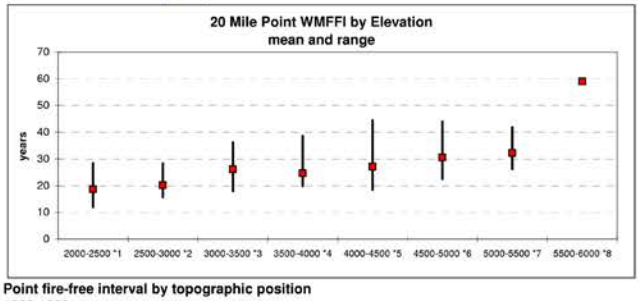


Point fire-free interval by elevation

1660-1889

Elevation	minimum	maximum	mean	SD	C of V	n
2000-2500 *1	11.94	28.52	18.64	4.97	0.27	12.00
2500-3000 *2	15.72	28.40	20.21	4.39	0.22	8.00
3000-3500 *3	17.94	36.26	26.10	6.82	0.26	8.00
3500-4000 *4	19.86	38.58	24.65	6.35	0.26	9.00
4000-4500 *5	18.47	44.51	27.10	8.34	0.31	10.00
4500-5000 *6	22.56	43.98	30.50	6.46	0.21	11.00
5000-5500 *7	26.27	41.86	32.18	5.86	0.18	5.00
5500-6000 *8			59.05			1.00

Elevation class 1 is significantly shorter than 5 (p=.053), 6 (p=.001), 7 (p=.004) a (p<.000). Class 2 is significantly shorter than 6 (p=.019), 7 (p=.032) and 8 (p<.000). Class 3, 4 and 5, are shorter than 8 (p<.000). Class 6 is shorter than 8 (p=.002). Class 7 is shorter than 8 (p=.006)



Point fire-free interval by topographic position

1660-1889

Topographic Position	minimum	maximum	mean	SD	C of V	n
Valley bottom	11.94	19.99	16.54	2.75	0.17	9
Lower 3rd	15.72	36.26	24.75	6.58	0.27	12
Middle 3rd	17.7	44.51	26.14	8	0.31	23
Upper 3rd	20	59.05	30.74	10.07	0.33	14
Ridgetop	18.47	36.74	27.51	7.36	0.27	6

Valley bottom is significantly shorter than Mid. 3rd (p=.021) and Upr. 3rd (p=.001) and somewhat shorter than Ridgetop (p=.068)

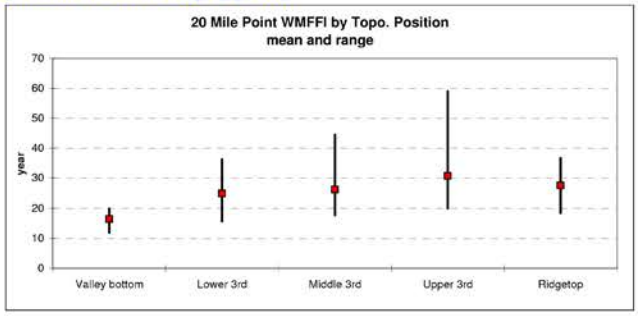
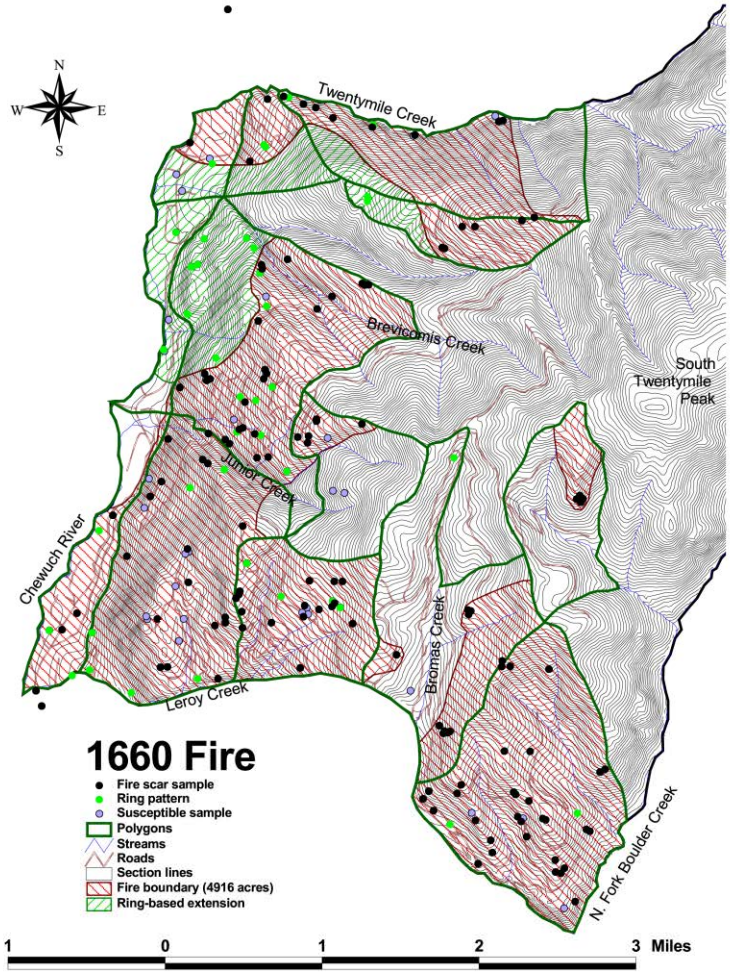


Figure 8. Summary of point Weibull median FFI by aspect, elevation, slope, and topographic class.


N
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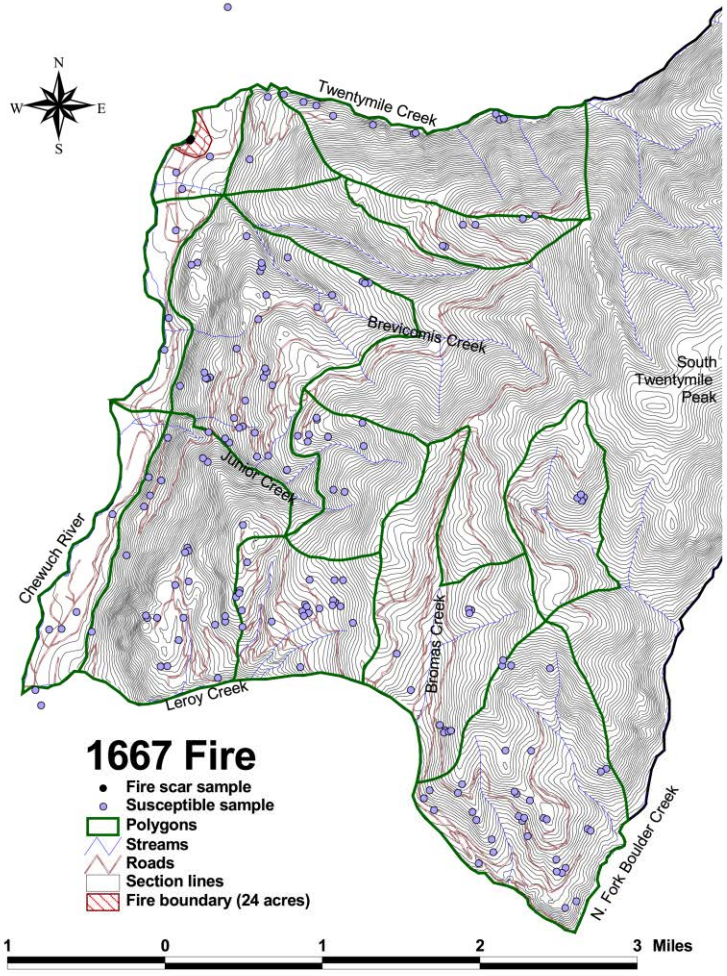
Twentymile Creek
Brevicomis Creek
South Twentymile Peak
Junior Creek
Chewuch River
Bromas Creek
Leroy Creek
N. Fork Boulder Creek
1660 Fire
Fire scar sample
Ring pattern
Susceptible sample
Polygons
Streams
Roads
Section lines
Fire boundary (4916 acres)
Ring-based extension
1 0 1 2 3 Miles


N
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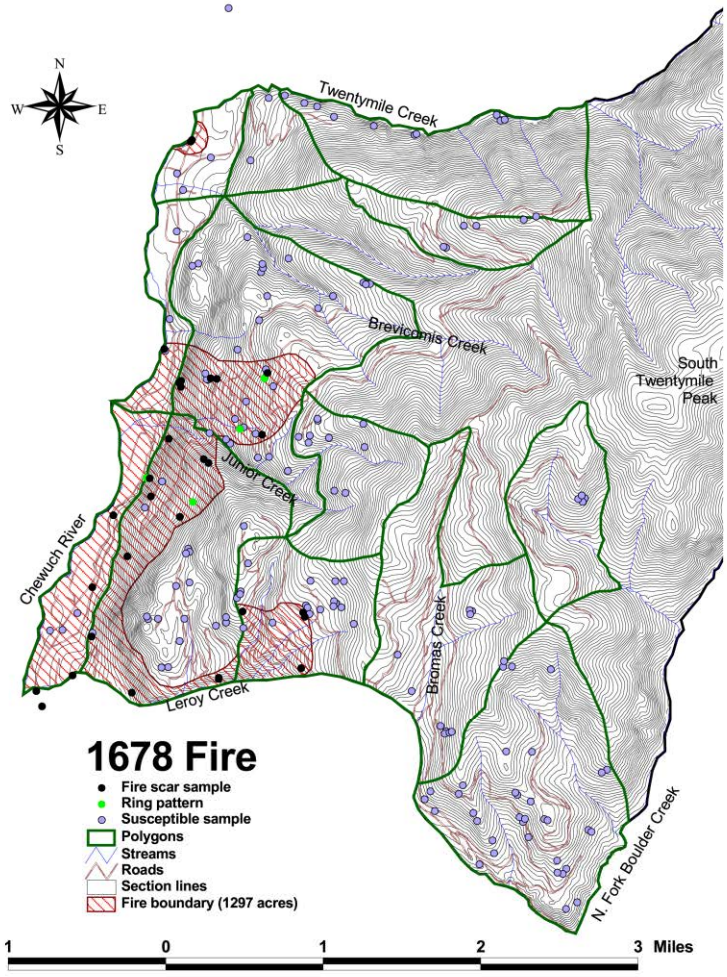
Twentymile Creek
Brevicomis Creek
South Twentymile Peak
Junior Creek
Chewuch River
Bromas Creek
Leroy Creek
N. Fork Boulder Creek
1667 Fire
Fire scar sample
Susceptible sample
Polygons
Streams
Roads
Section lines
Fire boundary (24 acres)
1 0 1 2 3 Miles


N
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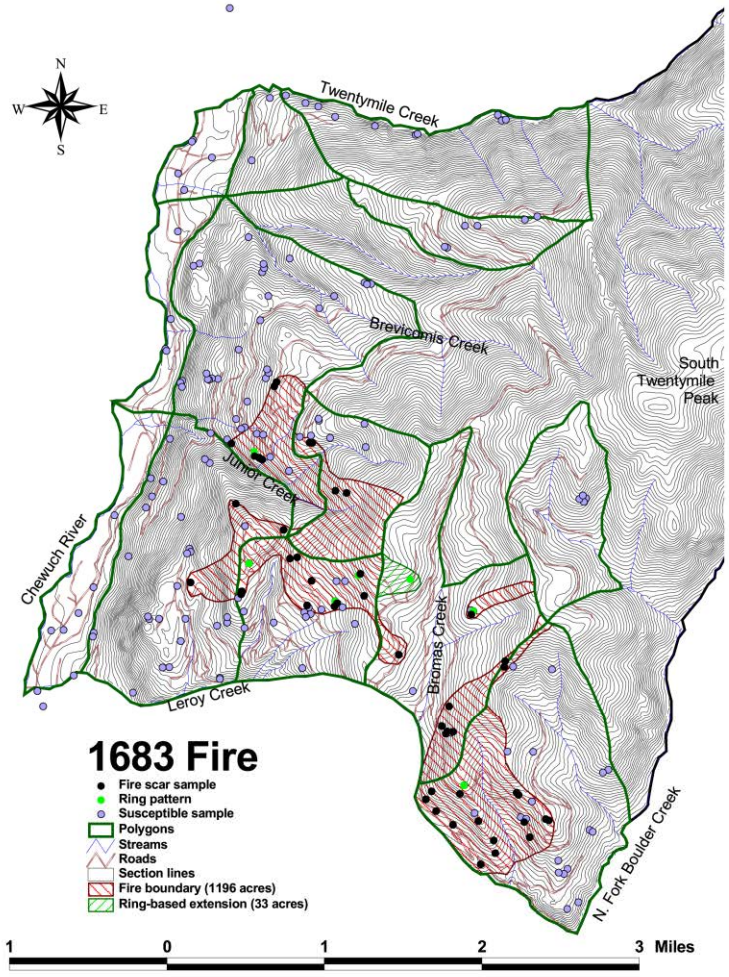
Twentymile Creek
Brevicomis Creek
South Twentymile Peak
Junior Creek
Chewuch River
Leroy Creek
Bromas Creek
N. Fork Boulder Creek
1678 Fire
Fire scar sample
Ring pattern
Susceptible sample
Polygons
Streams
Roads
Section lines
Fire boundary (1297 acres)
1 0 1 2 3 Miles


N
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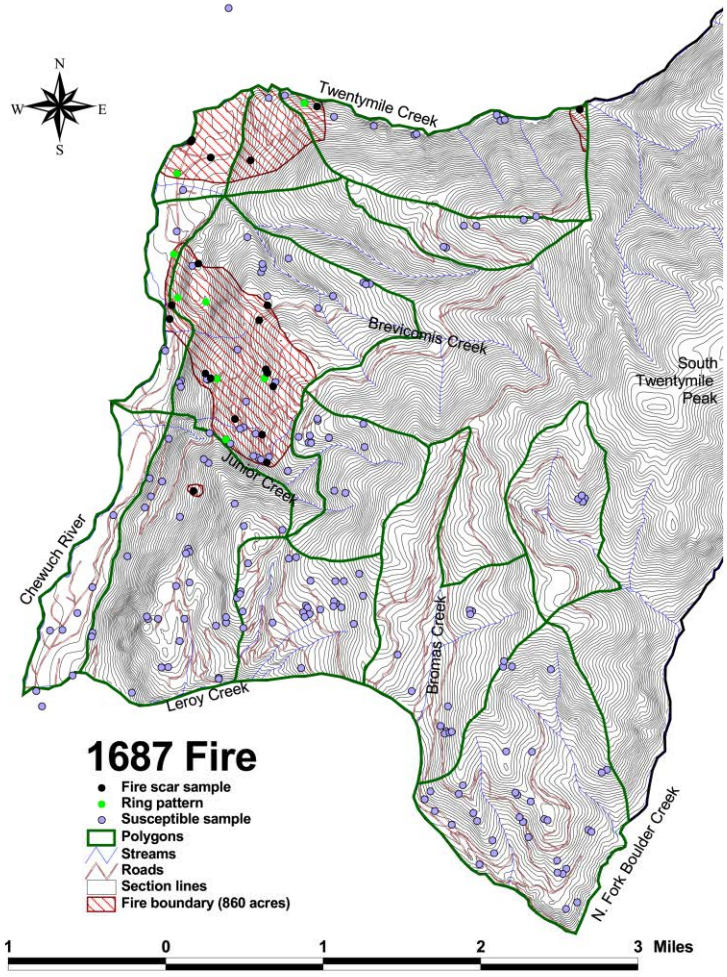
Twentymile Creek
Brevicomis Creek
South Twentymile Peak
Junior Creek
Chewuch River
Leroy Creek
Bromas Creek
N. Fork Boulder Creek
1683 Fire
Fire scar sample
Ring pattern
Susceptible sample
Polygons
Streams
Roads
Section lines
Fire boundary (1196 acres)
Ring-based extension (33 acres)
1 0 1 2 3 Miles


N
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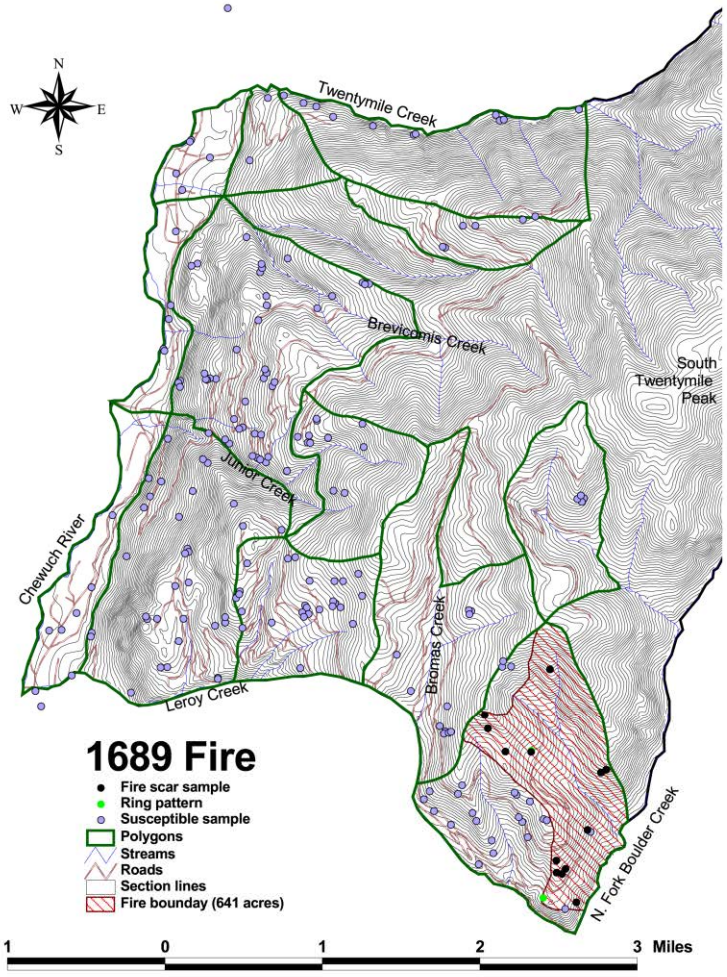
Twentymile Creek
Brevicomis Creek
South Twentymile Peak
Junior Creek
Chewuch River
Leroy Creek
Bromas Creek
N. Fork Boulder Creek
1687 Fire
Fire scar sample
Ring pattern
Susceptible sample
Polygons
Streams
Roads
Section lines
Fire boundary (860 acres)
1 0 1 2 3 Miles


N
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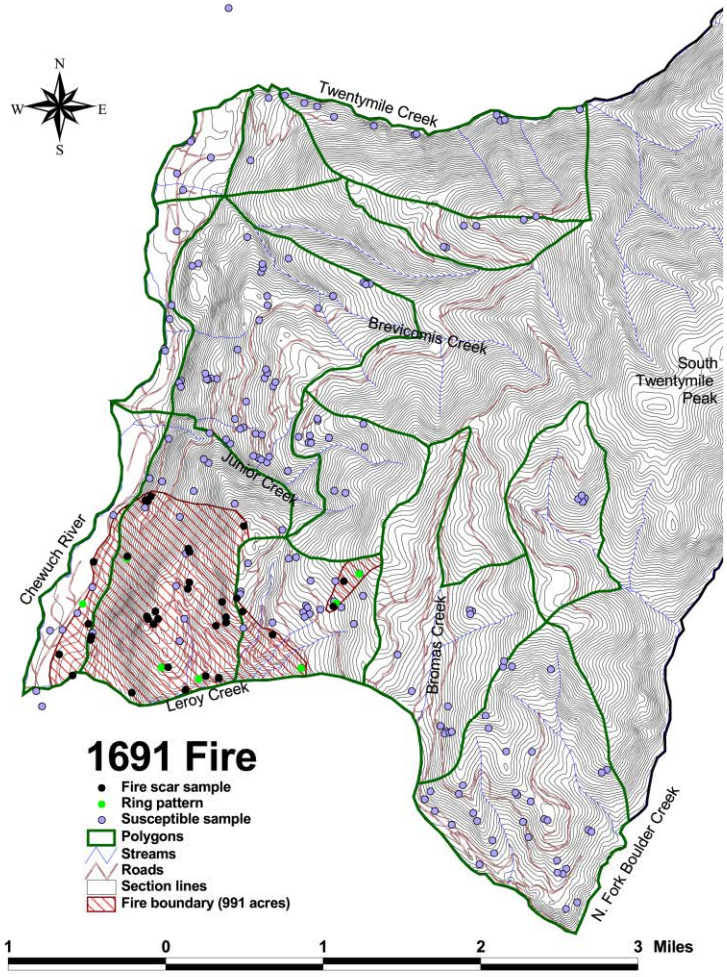
Twentymile Creek
Brevicomis Creek
South Twentymile Peak
Junior Creek
Chewuch River
Leroy Creek
Bromas Creek
N. Fork Boulder Creek
1689 Fire
Fire scar sample
Ring pattern
Susceptible sample
Polygons
Streams
Roads
Section lines
Fire bounday (641 acres)
1 0 1 2 3 Miles


N
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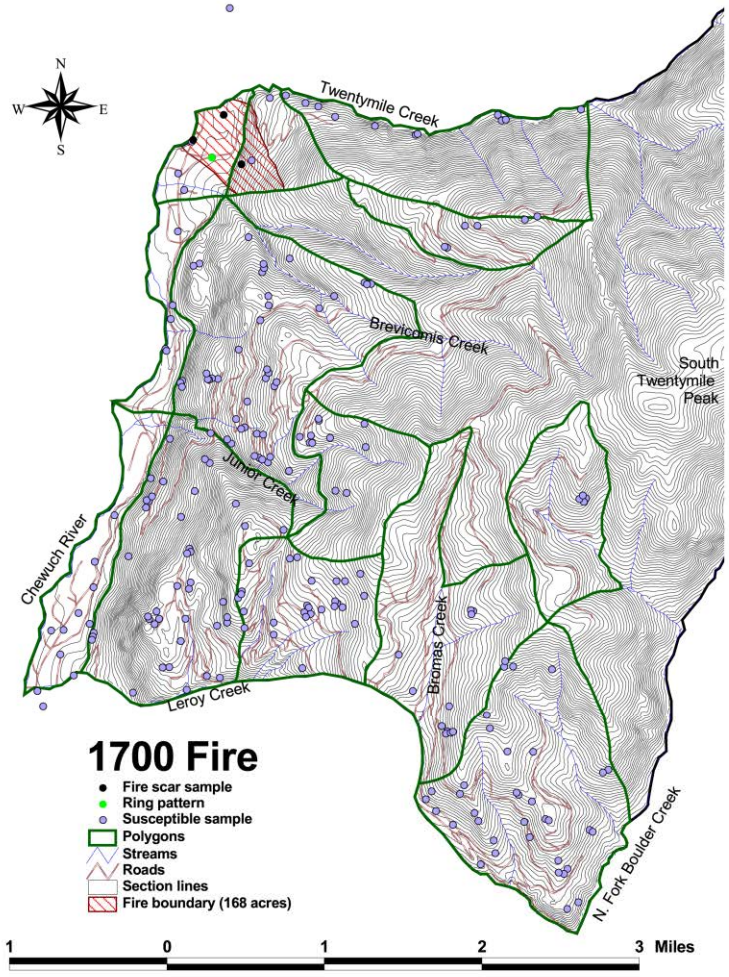
Twentymile Creek
Brevicomis Creek
South Twentymile Peak
Junior Creek
Chewuch River
Bromas Creek
Leroy Creek
N. Fork Boulder Creek
1691 Fire
Fire scar sample
Ring pattern
Susceptible sample
Polygons
Streams
Roads
Section lines
Fire boundary (991 acres)
1 0 1 2 3 Miles


N
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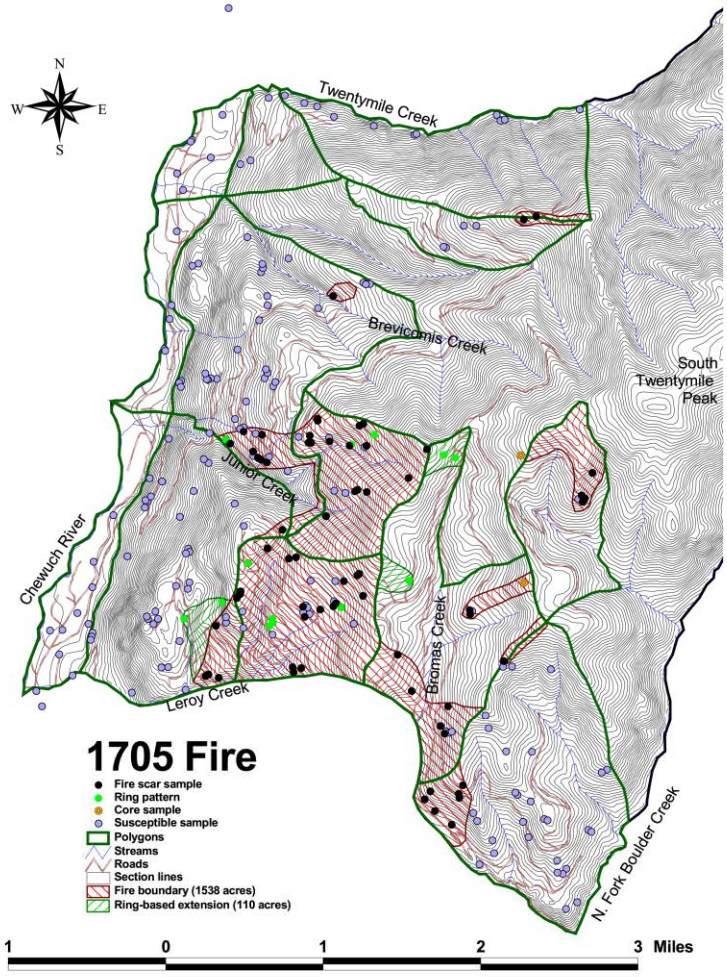
Twentymile Creek
Brevicomis Creek
South Twentymile Peak
Junior Creek
Chewuch River
Bromas Creek
Leroy Creek
N. Fork Boulder Creek
1700 Fire
Fire scar sample
Ring pattern
Susceptible sample
Polygons
Streams
Roads
Section lines
Fire boundary (168 acres)
1 0 1 2 3 Miles


N
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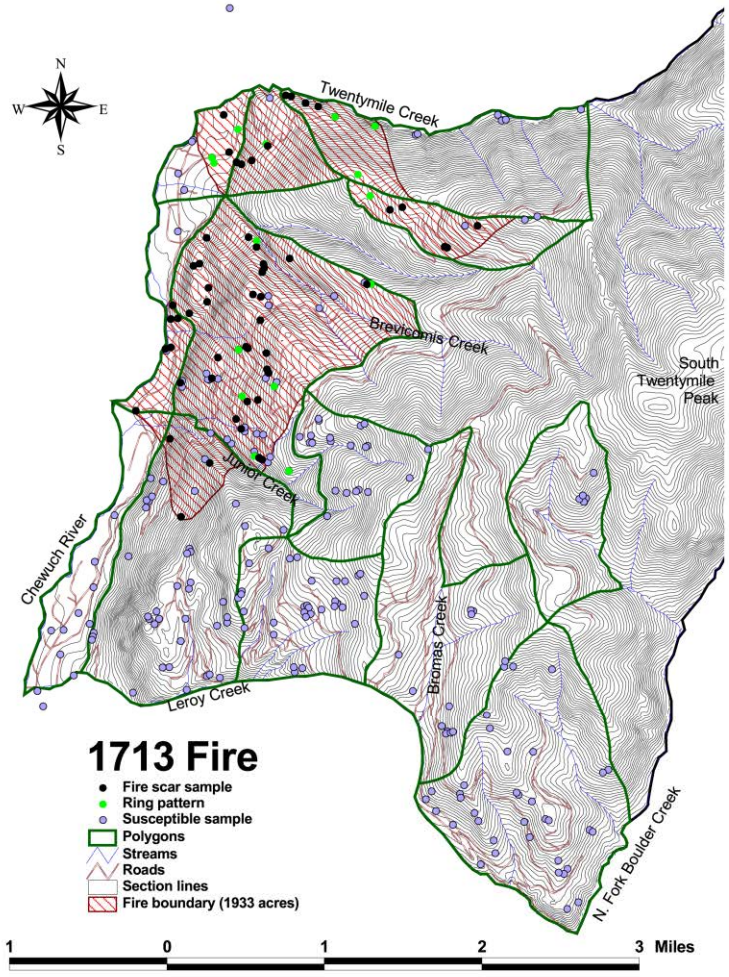
Twentymile Creek
Brevicomis Creek
South Twentymile Peak
Junior Creek
Chewuch River
Bromas Creek
Leroy Creek
N. Fork Boulder Creek
1705 Fire
Fire scar sample
Ring pattern
Core sample
Susceptible sample
Polygons
Streams
Roads
Section lines
Fire boundary (1538 acres)
Ring-based extension (110 acres)
1 0 1 2 3 Miles


N
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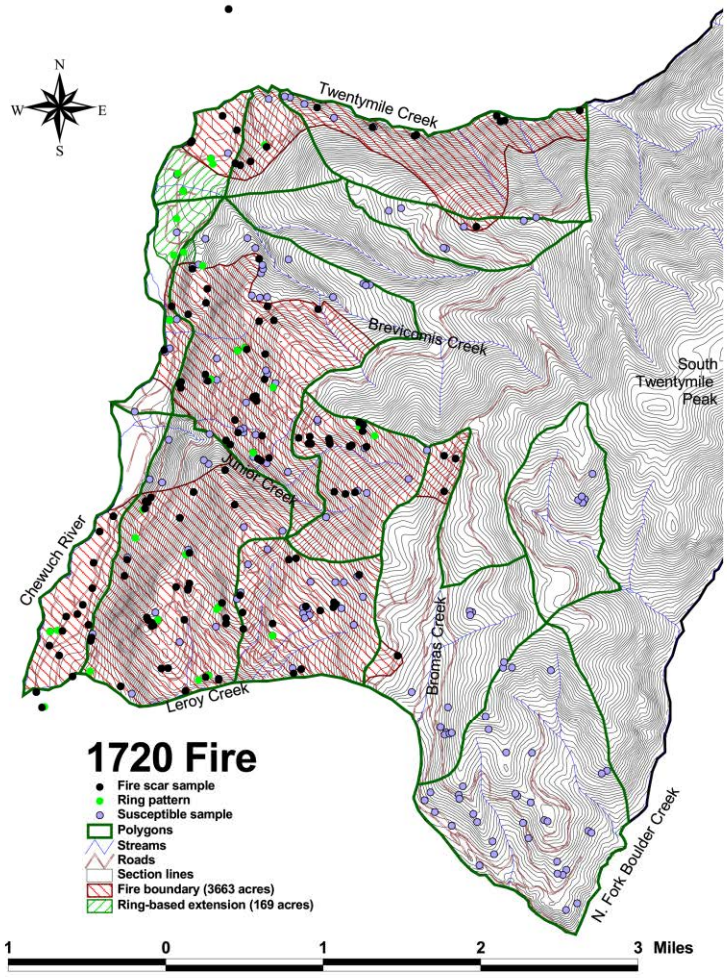
Twentymile Creek
Brevicomis Creek
South Twentymile Peak
Junior Creek
Chewuch River
Bromas Creek
Leroy Creek
N. Fork Boulder Creek
1713 Fire
Fire scar sample
Ring pattern
Susceptible sample
Polygons
Streams
Roads
Section lines
Fire boundary (1933 acres)
1 0 1 2 3 Miles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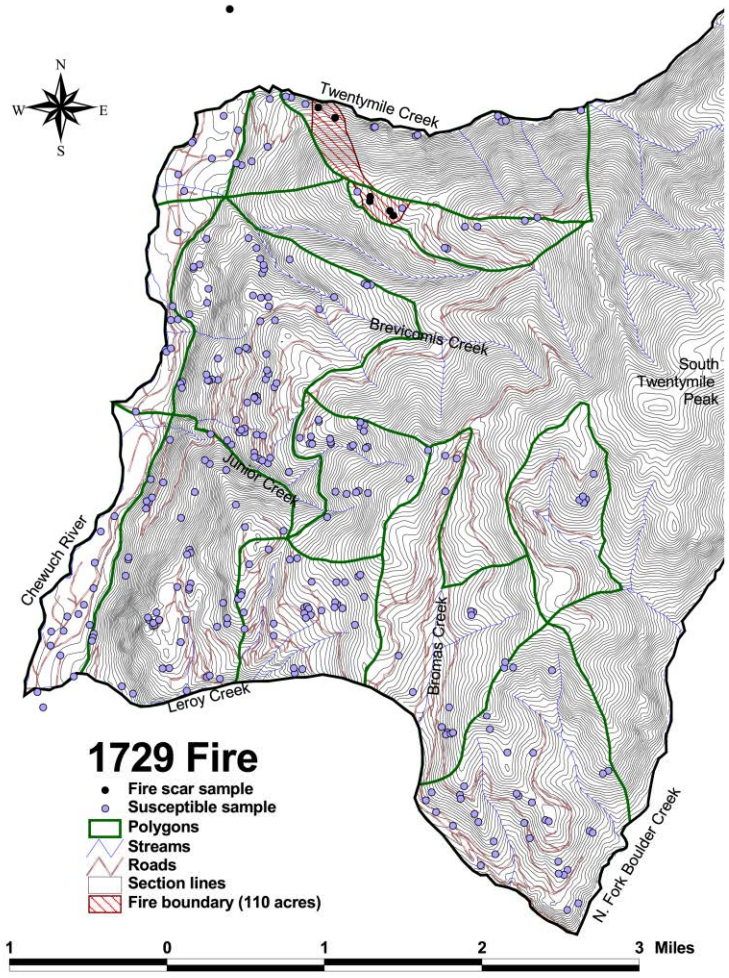
Twentymile Creek
Brevicomis Creek
South Twentymile Peak
Junior Creek
Chewuch River
Bromas Creek
Leroy Creek
N. Fork Boulder Creek
1720 Fire
Fire scar sample
Ring pattern
Susceptible sample
Polygons
Streams
Roads
Section lines
Fire boundary (3663 acres)
Ring-based extension (169 acres)
1 0 1 2 3 Miles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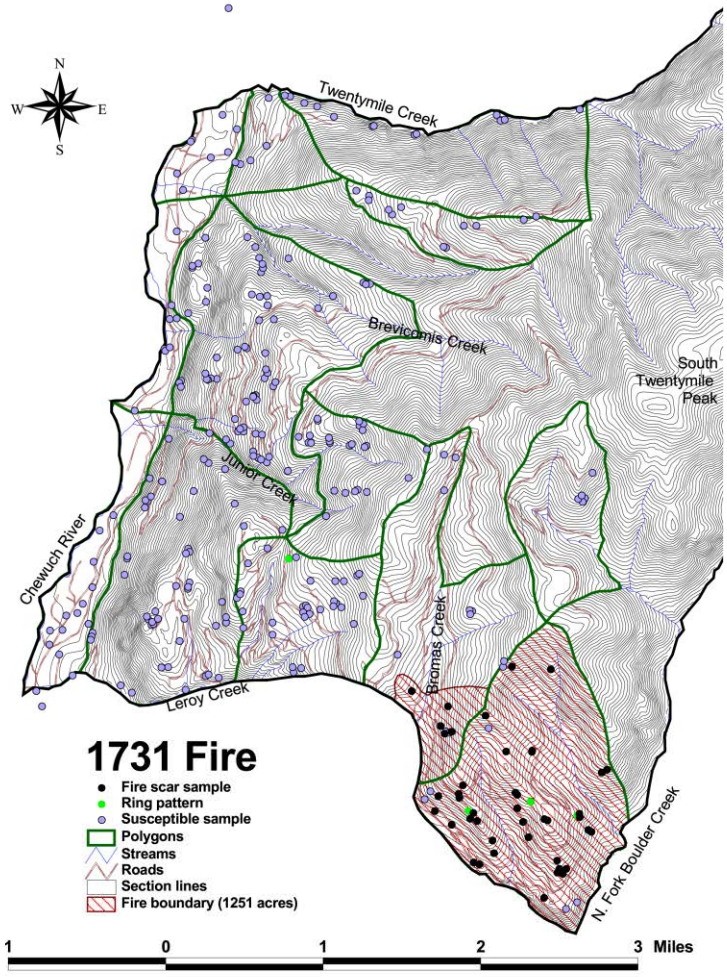
Twentymile Creek
Brevicomis Creek
South Twentymile Peak
Junior Creek
Chewuch River
Bromas Creek
Leroy Creek
N. Fork Boulder Creek
1729 Fire
Fire scar sample
Susceptible sample
Polygons
Streams
Roads
Section lines
Fire boundary (110 acres)
1 0 1 2 3 Miles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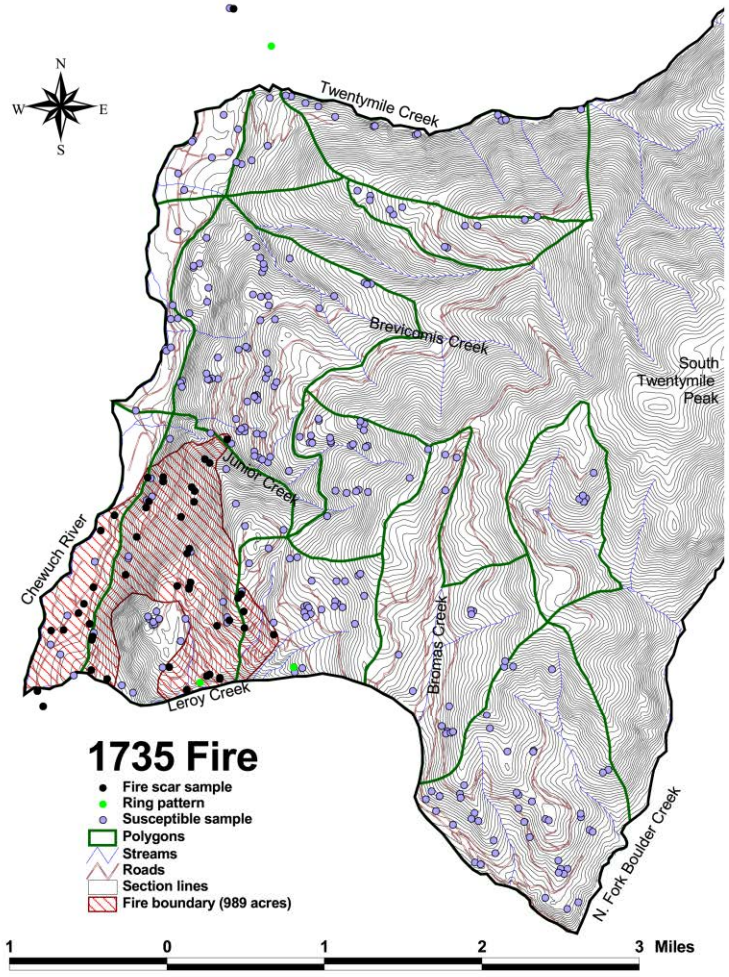
Twentymile Creek
Brevicomis Creek
South Twentymile Peak
Junior Creek
Chewuch River
Bromas Creek
Leroy Creek
N. Fork Boulder Creek
1731 Fire
Fire scar sample
Ring pattern
Susceptible sample
Polygons
Streams
Roads
Section lines
Fire boundary (1251 acres)
1 0 1 2 3 Miles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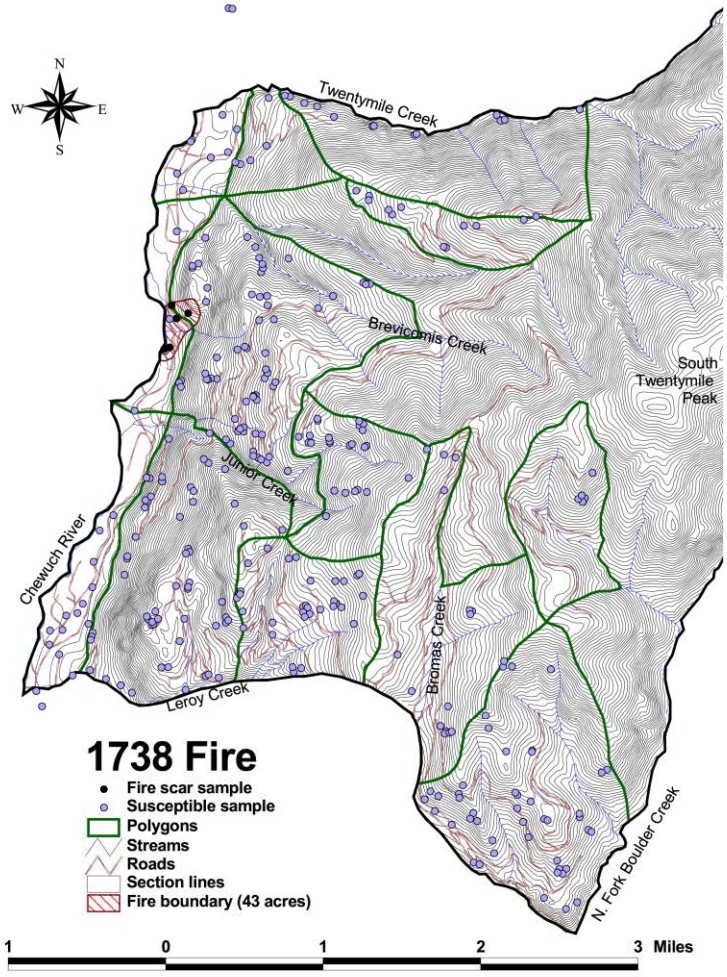
Twentymile Creek
Brevicomis Creek
South Twentymile Peak
Junior Creek
Chewuch River
Bromas Creek
Leroy Creek
N. Fork Boulder Creek
1735 Fire
Fire scar sample
Ring pattern
Susceptible sample
Polygons
Streams
Roads
Section lines
Fire boundary (989 acres)
1 0 1 2 3 Miles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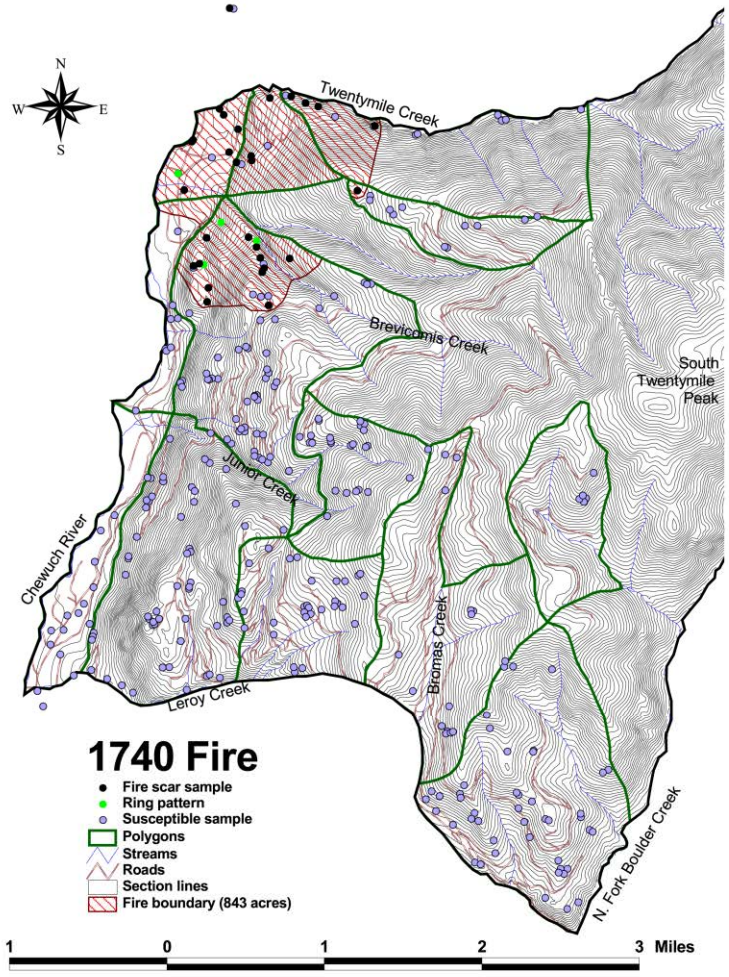
Twentymile Creek
Brevicomis Creek
South Twentymile Peak
Junior Creek
Chewuch River
Bromas Creek
Leroy Creek
N. Fork Boulder Creek
1738 Fire
Fire scar sample
Susceptible sample
Polygons
Streams
Roads
Section lines
Fire boundary (43 acres)
1 0 1 2 3 Miles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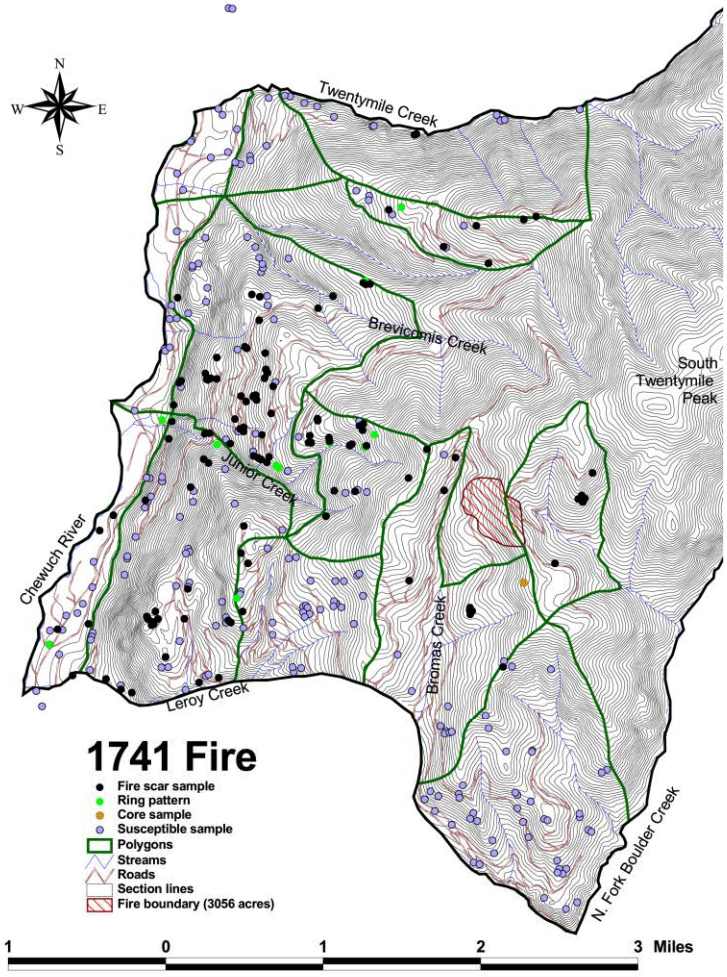
Twentymile Creek
Brevicomis Creek
South Twentymile Peak
Junior Creek
Chewuch River
Bromas Creek
Leroy Creek
N. Fork Boulder Creek
1740 Fire
Fire scar sample
Ring pattern
Susceptible sample
Polygons
Streams
Roads
Section lines
Fire boundary (843 acres)
1 0 1 2 3 Miles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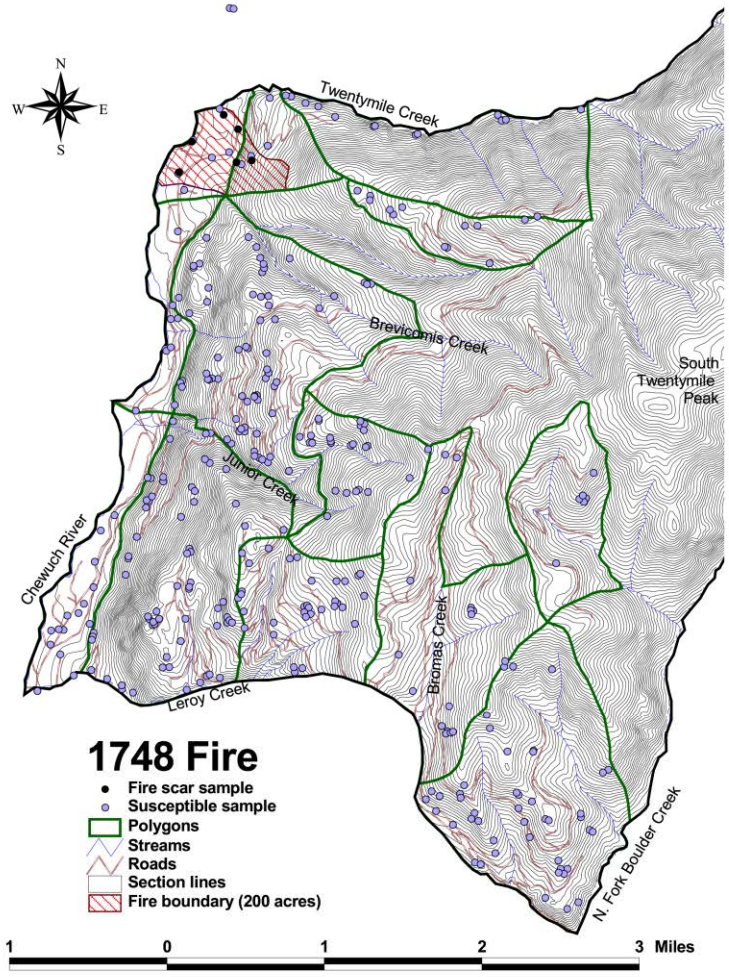
Twentymile Creek
Brevicomis Creek
South Twentymile Peak
Junior Creek
Chewuch River
Leroy Creek
Bromas Creek
N. Fork Boulder Creek
1741 Fire
Fire scar sample
Ring pattern
Core sample
Susceptible sample
Polygons
Streams
Roads
Section lines
Fire boundary (3056 acres)
1 0 1 2 3 Miles


N
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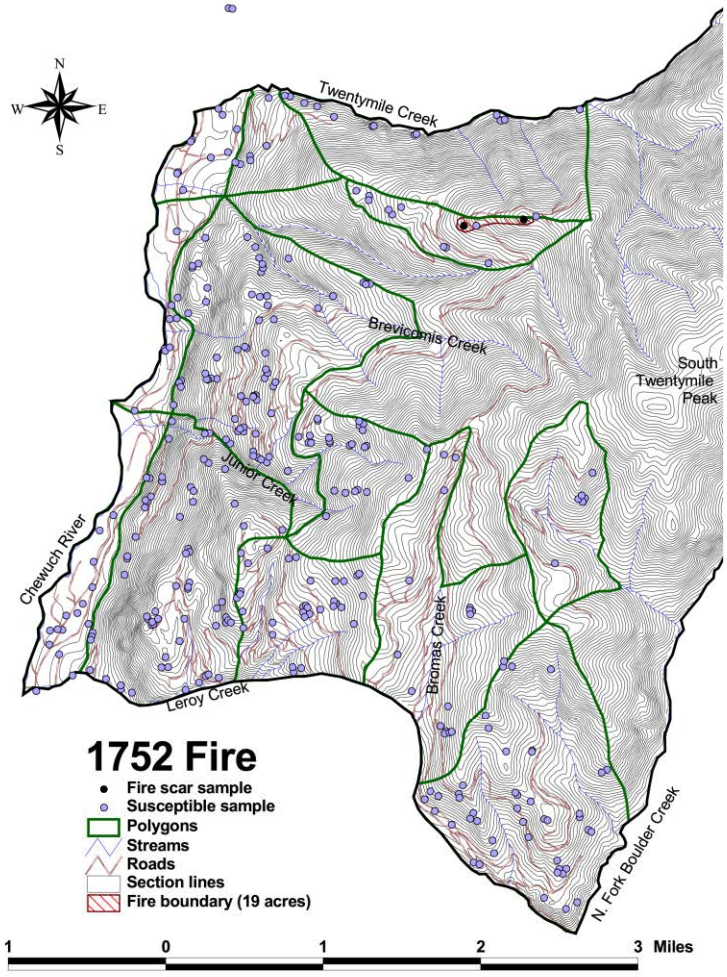
Twentymile Creek
Brevicomis Creek
South Twentymile Peak
Junior Creek
Chewuch River
Leroy Creek
Bromas Creek
N. Fork Boulder Creek
1748 Fire
Fire scar sample
Susceptible sample
Polygons
Streams
Roads
Section lines
Fire boundary (200 acres)
1 0 1 2 3 Miles


N
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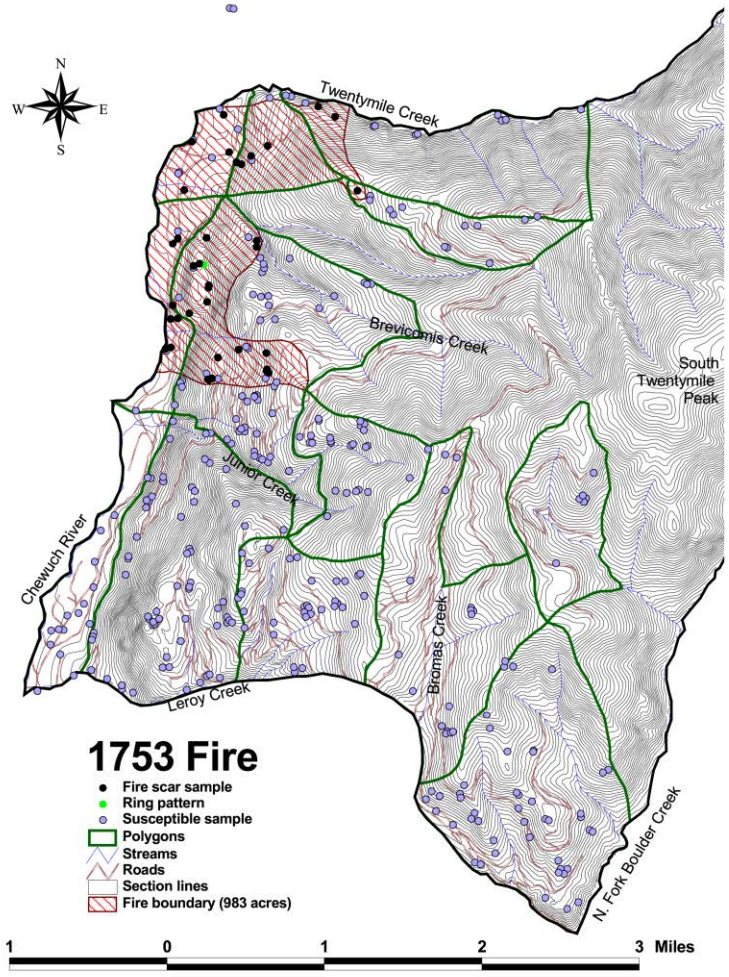
Twentymile Creek
Brevicomis Creek
South Twentymile Peak
Junior Creek
Chewuch River
Bromas Creek
Leroy Creek
N. Fork Boulder Creek
1752 Fire
Fire scar sample
Susceptible sample
Polygons
Streams
Roads
Section lines
Fire boundary (19 acres)
1 0 1 2 3 Miles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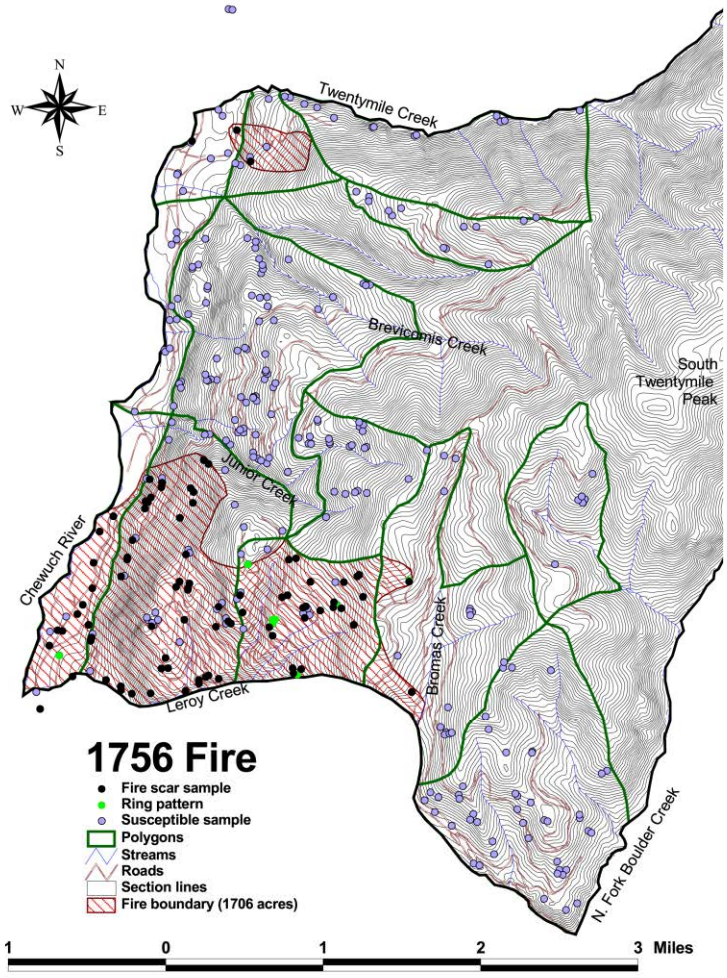
Twentymile Creek
Brevicomis Creek
South Twentymile Peak
Junior Creek
Chewuch River
Bromas Creek
Leroy Creek
N. Fork Boulder Creek
1753 Fire
Fire scar sample
Ring pattern
Susceptible sample
Polygons
Streams
Roads
Section lines
Fire boundary (983 acres)
1 0 1 2 3 Miles


N
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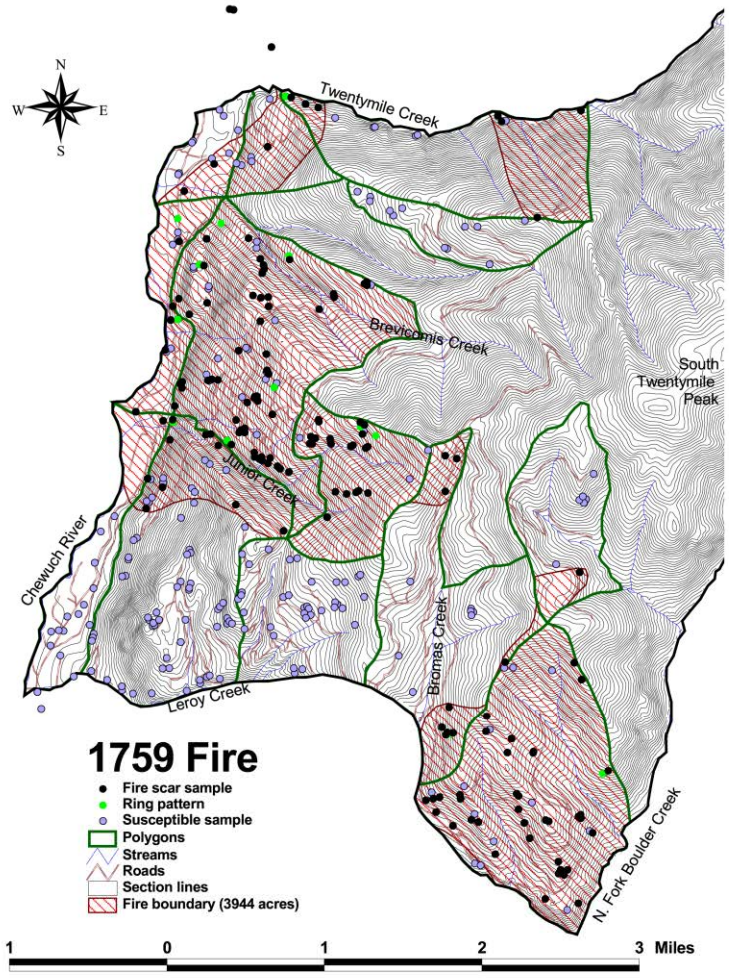
Twentymile Creek
Brevicomis Creek
South Twentymile Peak
Junior Creek
Chewuch River
Bromas Creek
Leroy Creek
N. Fork Boulder Creek
1756 Fire
Fire scar sample
Ring pattern
Susceptible sample
Polygons
Streams
Roads
Section lines
Fire boundary (1706 acres)
1 0 1 2 3 Miles


N
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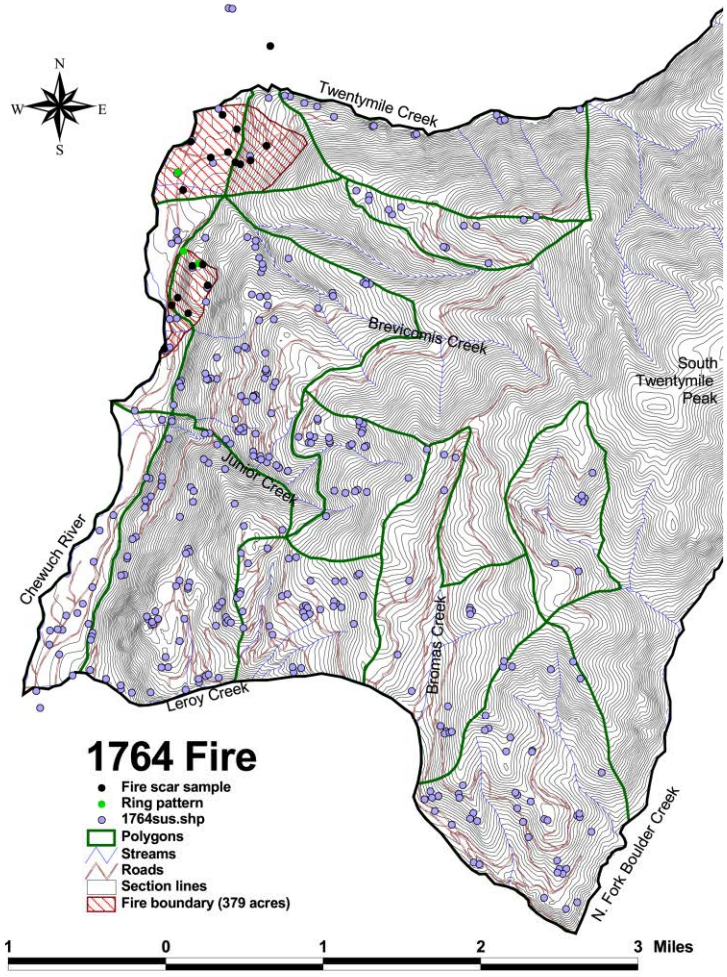
Twentymile Creek
Brevicomis Creek
South Twentymile Peak
Junior Creek
Chewuch River
Bromas Creek
Leroy Creek
N. Fork Boulder Creek
1759 Fire
Fire scar sample
Ring pattern
Susceptible sample
Polygons
Streams
Roads
Section lines
Fire boundary (3944 acres)
1 0 1 2 3 Miles


N
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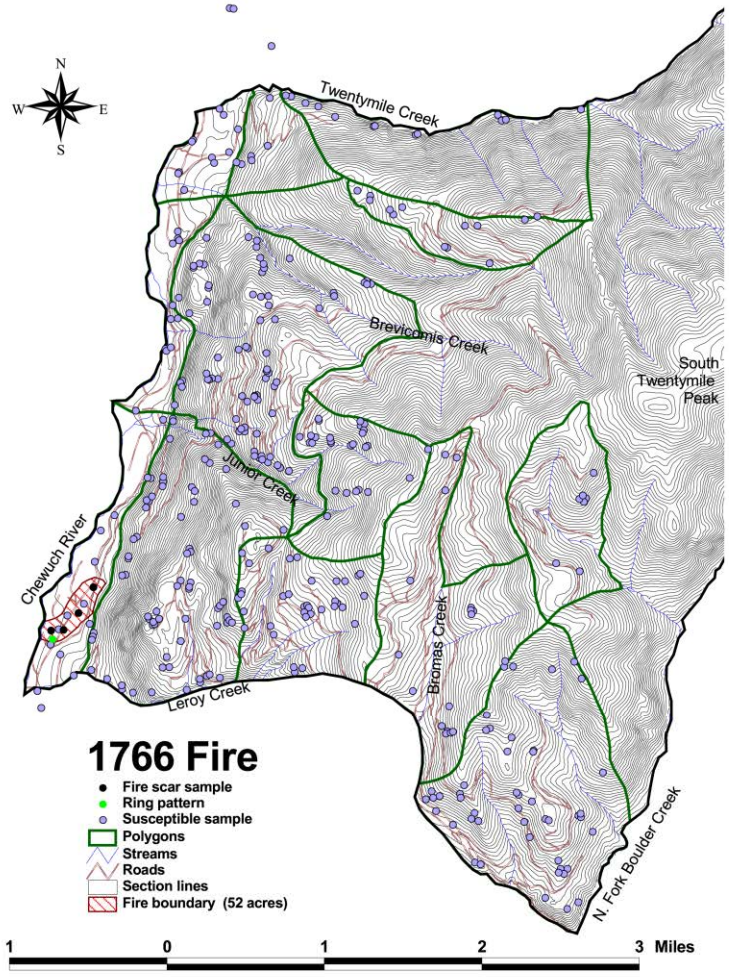
Twentymile Creek
Brevicomis Creek
South Twentymile Peak
Junior Creek
Chewuch River
Leroy Creek
Bromas Creek
N. Fork Boulder Creek
1764 Fire
Fire scar sample
Ring pattern
1764sus.shp
Polygons
Streams
Roads
Section lines
Fire boundary (379 acres)
1 0 1 2 3 Miles


N
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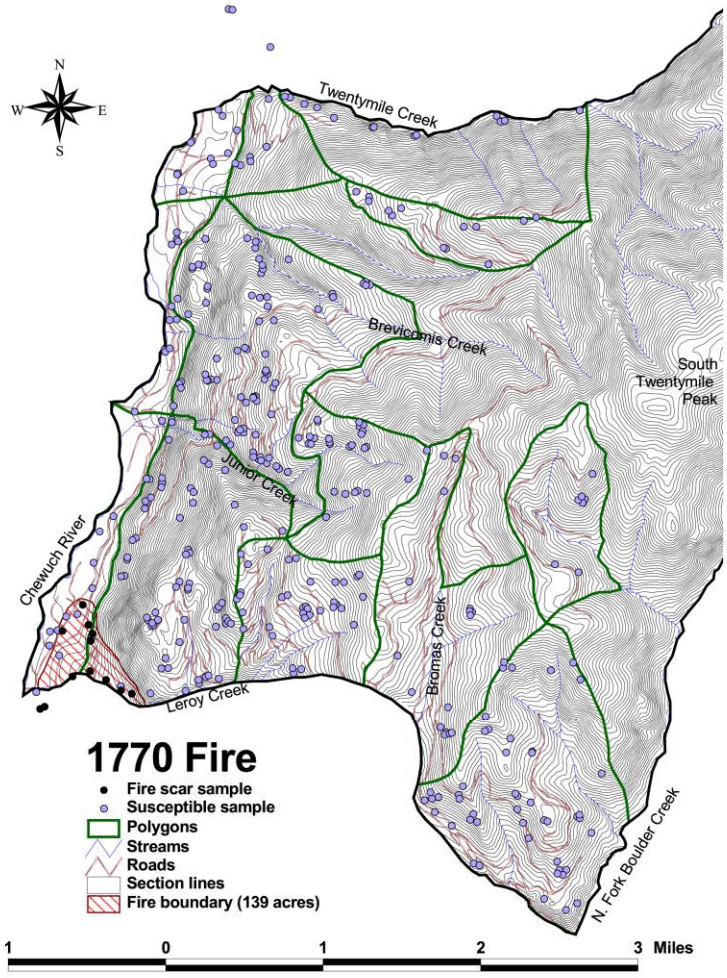
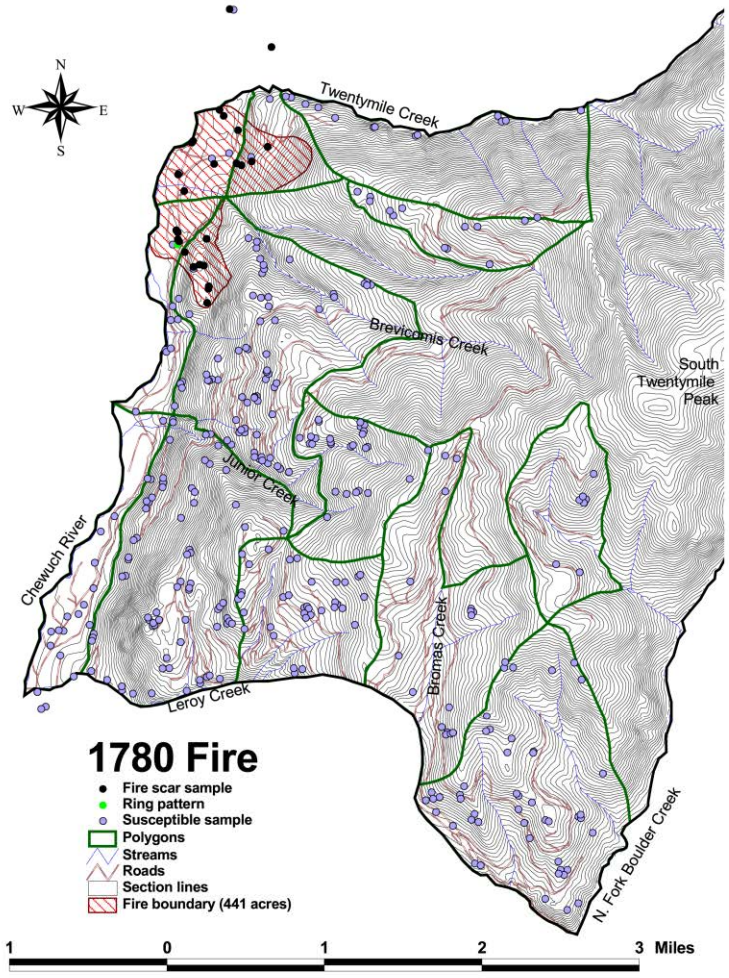
Twentymile Creek
Brevicomis Creek
South Twentymile Peak
Junior Creek
Chewuch River
Leroy Creek
Bromas Creek
N. Fork Boulder Creek
1766 Fire
Fire scar sample
Ring pattern
Susceptible sample
Polygons
Streams
Roads
Section lines
Fire boundary (52 acres)
1 0 1 2 3 Miles


N
W
E
S
Twentymile Creek
Brevicomis Creek
South Twentymile Peak
Junior Creek
Chewuch River
Leroy Creek
Bromas Creek
N. Fork Boulder Creek
1770 Fire
Fire scar sample
Susceptible sample
Polygons
Streams
Roads
Section lines
Fire boundary (139 acres)
1 0 1 2 3 Miles


N
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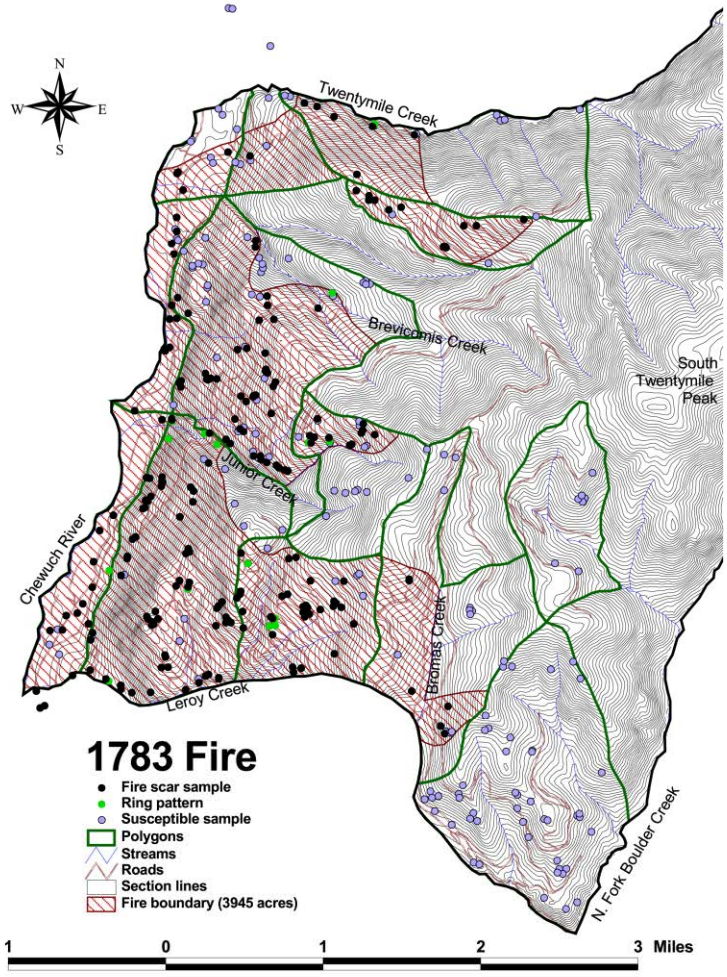
Twentymile Creek
Brevicomis Creek
South Twentymile Peak
Junior Creek
Chewuch River
Leroy Creek
Bromas Creek
N. Fork Boulder Creek
1780 Fire
Fire scar sample
Ring pattern
Susceptible sample
Polygons
Streams
Roads
Section lines
Fire boundary (441 acres)
1 0 1 2 3 Miles


N
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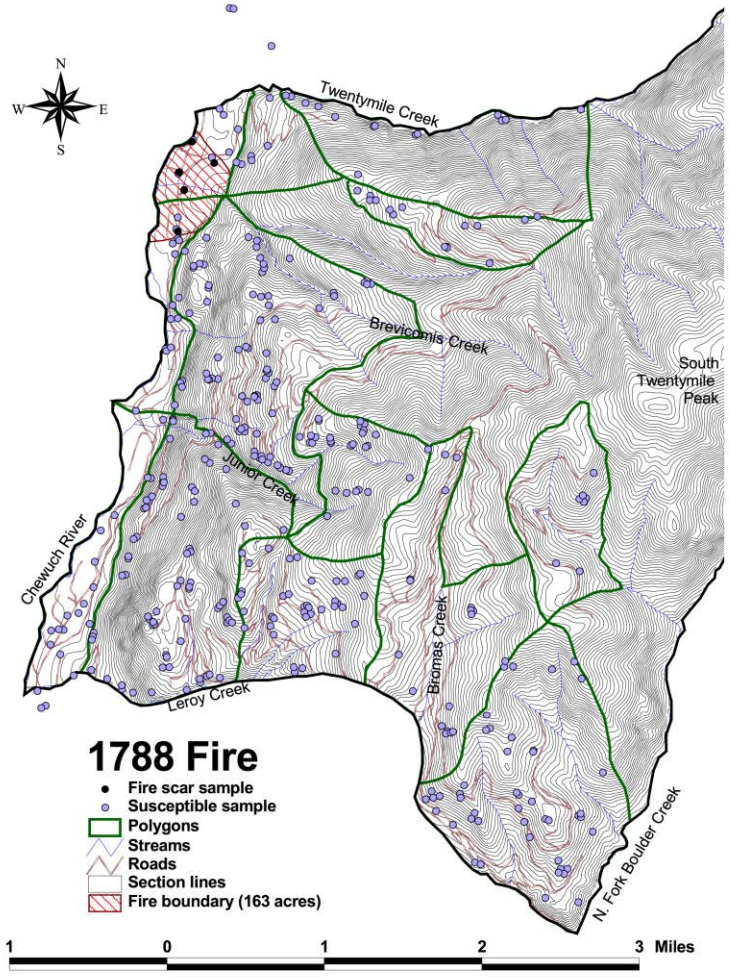
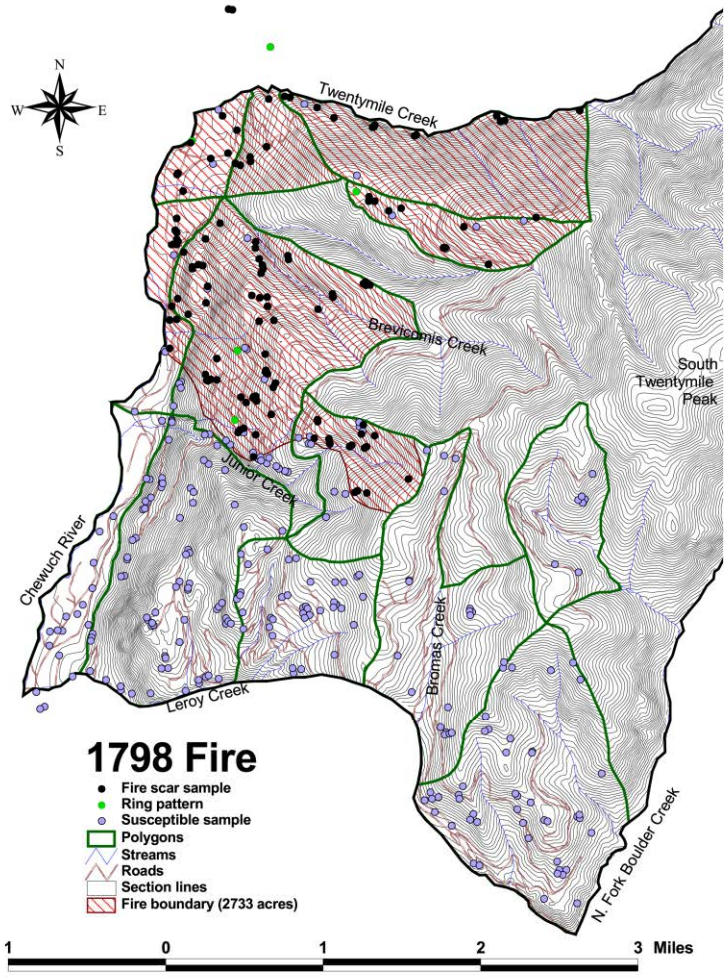
S
Twentymile Creek
Brevicomis Creek
South Twentymile Peak
Junior Creek
Chewuch River
Bromas Creek
Leroy Creek
N. Fork Boulder Creek
1783 Fire
Fire scar sample
Ring pattern
Susceptible sample
Polygons
Streams
Roads
Section lines
Fire boundary (3945 acres)
1 0 1 2 3 Miles


N
W
E
S
Twentymile Creek
Brevicomis Creek
South Twentymile Peak
Junior Creek
Chewuch River
Bromas Creek
Leroy Creek
N. Fork Boulder Creek
1788 Fire
Fire scar sample
Susceptible sample
Polygons
Streams
Roads
Section lines
Fire boundary (163 acres)
1 0 1 2 3 Miles


N
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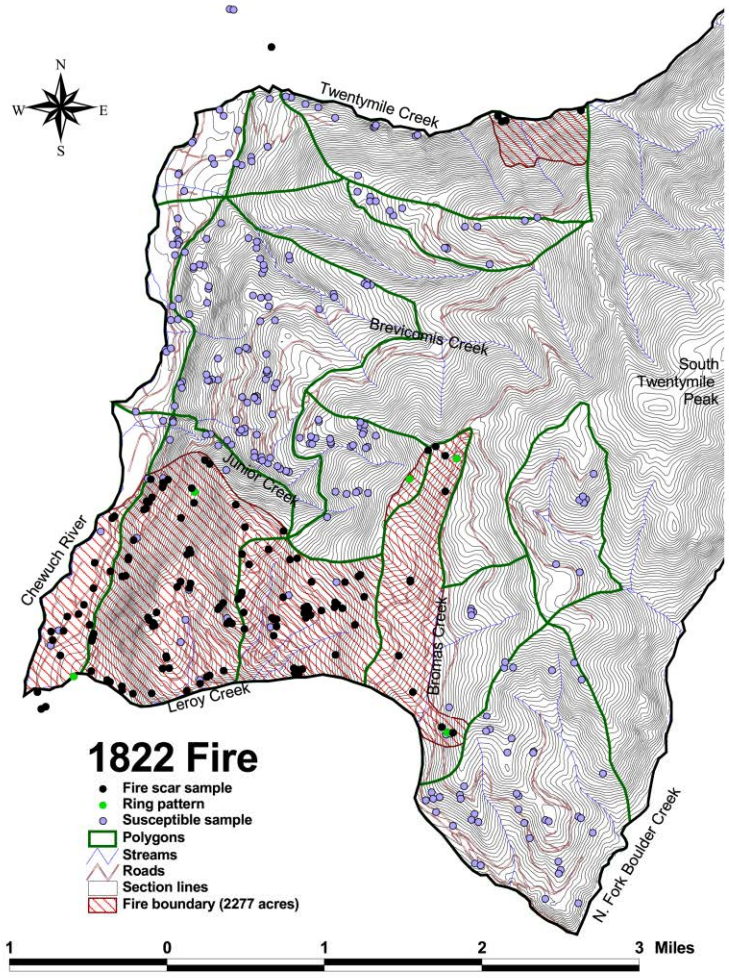
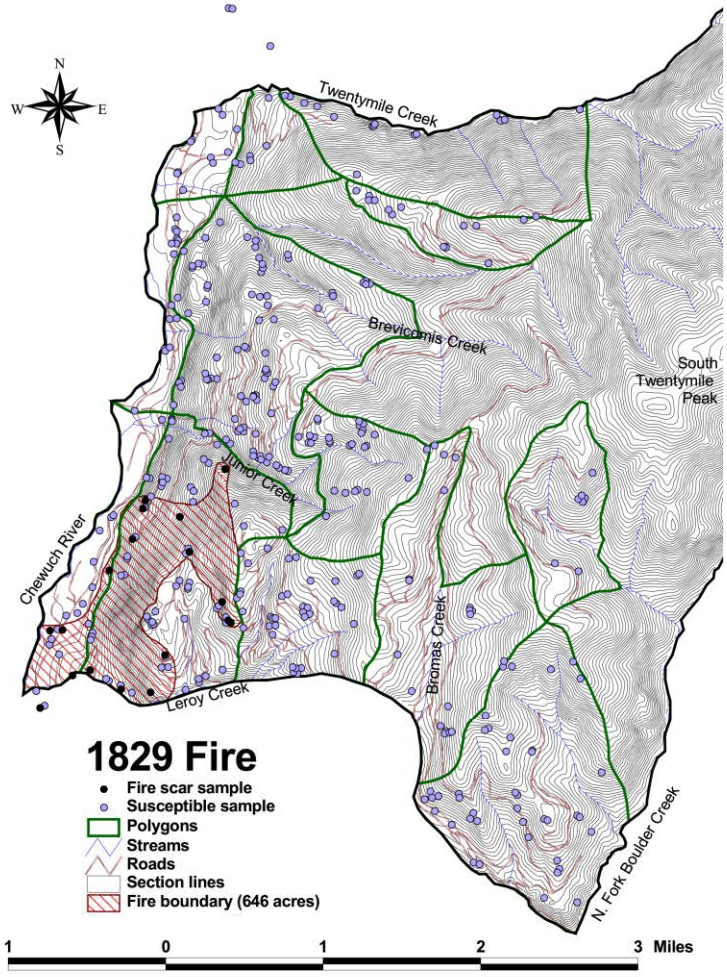
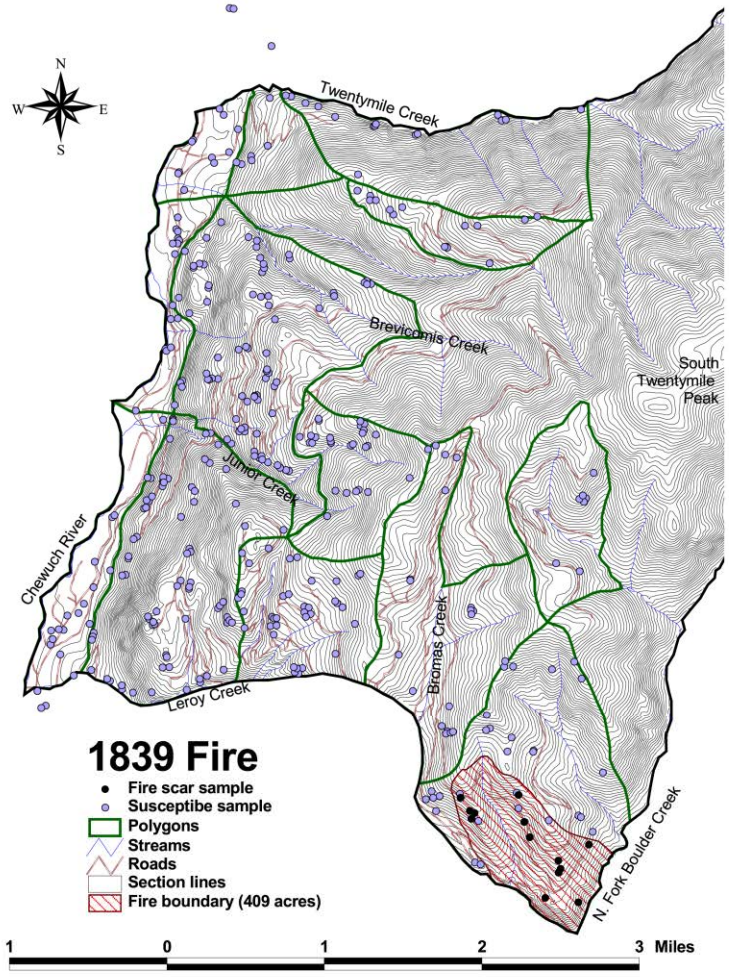
S
Twentymile Creek
Brevicomis Creek
South Twentymile Peak
Junior Creek
Chewuch River
Leroy Creek
Bromas Creek
N. Fork Boulder Creek
1798 Fire
Fire scar sample
Ring pattern
Susceptible sample
Polygons
Streams
Roads
Section lines
Fire boundary (2733 acres)
1 0 1 2 3 Miles


N
W
E
S
Twentymile Creek
Brevicomis Creek
South Twentymile Peak
Junior Creek
Chewuch River
Leroy Creek
Bromas Creek
N. Fork Boulder Creek
1822 Fire
Fire scar sample
Ring pattern
Susceptible sample
Polygons
Streams
Roads
Section lines
Fire boundary (2277 acres)
1 0 1 2 3 Miles


N
W
E
S
Twentymile Creek
Brevicomis Creek
South Twentymile Peak
Junior Creek
Chewuch River
Bromas Creek
Leroy Creek
N. Fork Boulder Creek
1829 Fire
Fire scar sample
Susceptible sample
Polygons
Streams
Roads
Section lines
Fire boundary (646 acres)
1 0 1 2 3 Miles


N
W
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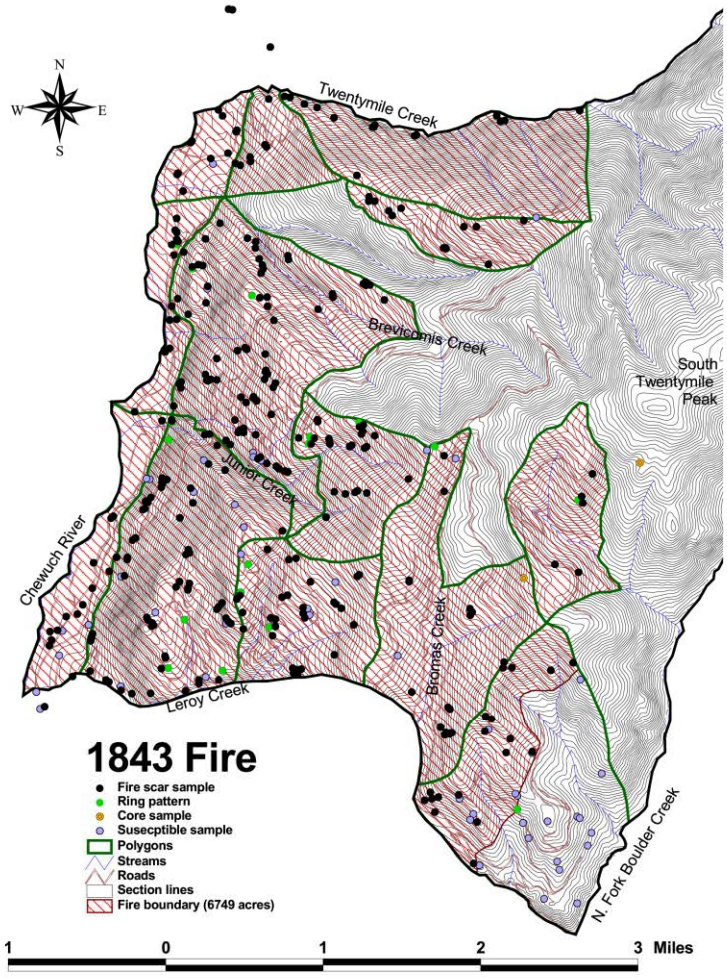
Twentymile Creek
Brevicomis Creek
South Twentymile Peak
Junior Creek
Chewuch River
Bromas Creek
Leroy Creek
N. Fork Boulder Creek
1839 Fire
Fire scar sample
Susceptibe sample
Polygons
Streams
Roads
Section lines
Fire boundary (409 acres)
1 0 1 2 3 Miles


N
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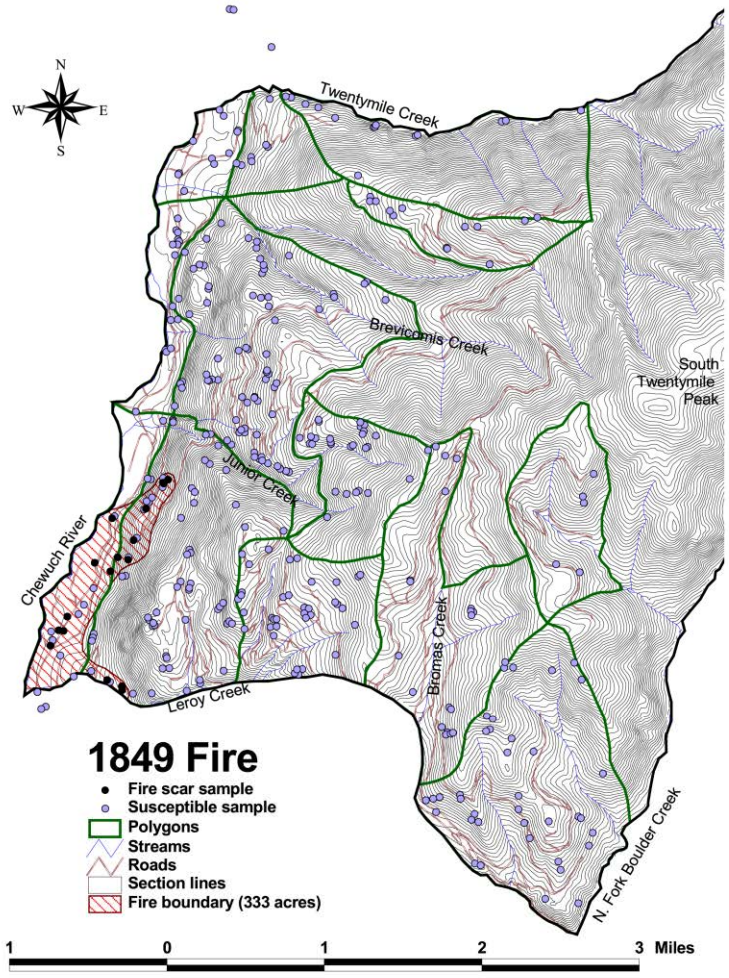
Twentymile Creek
Brevicomis Creek
South Twentymile Peak
Junior Creek
Chewuch River
Bromas Creek
Leroy Creek
N. Fork Boulder Creek
1843 Fire
Fire scar sample
Ring pattern
Core sample
Susecptible sample
Polygons
Streams
Roads
Section lines
Fire boundary (6749 acres)
1 0 1 2 3 Miles


N
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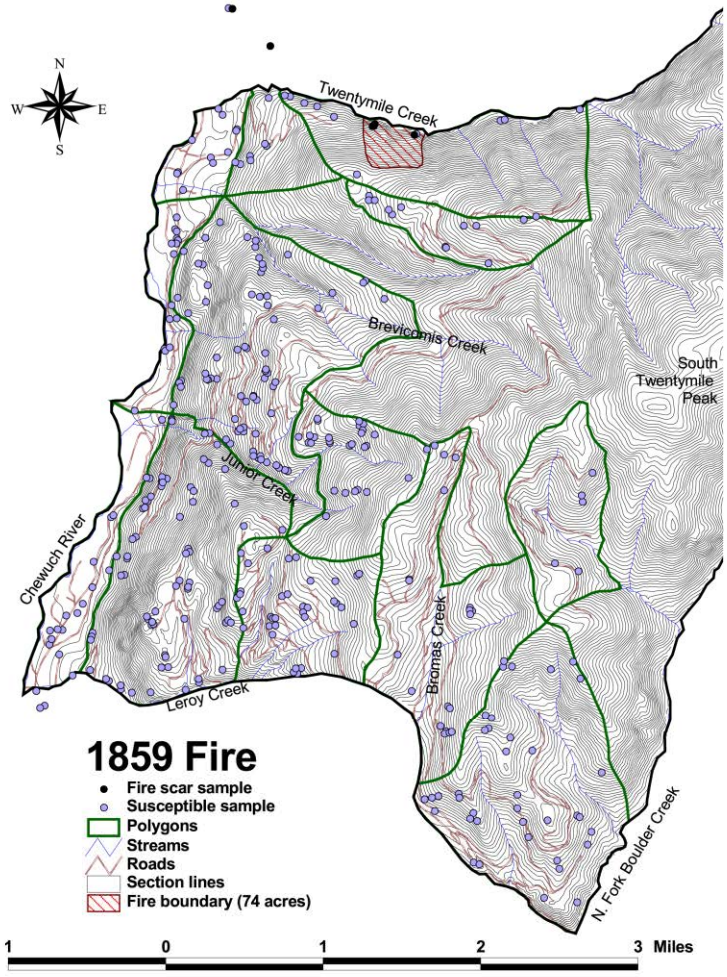
Twentymile Creek
Brevicomis Creek
South Twentymile Peak
Junior Creek
Chewuch River
Bromas Creek
Leroy Creek
N. Fork Boulder Creek
1849 Fire
Fire scar sample
Susceptible sample
Polygons
Streams
Roads
Section lines
Fire boundary (333 acres)
1 0 1 2 3 Miles


N
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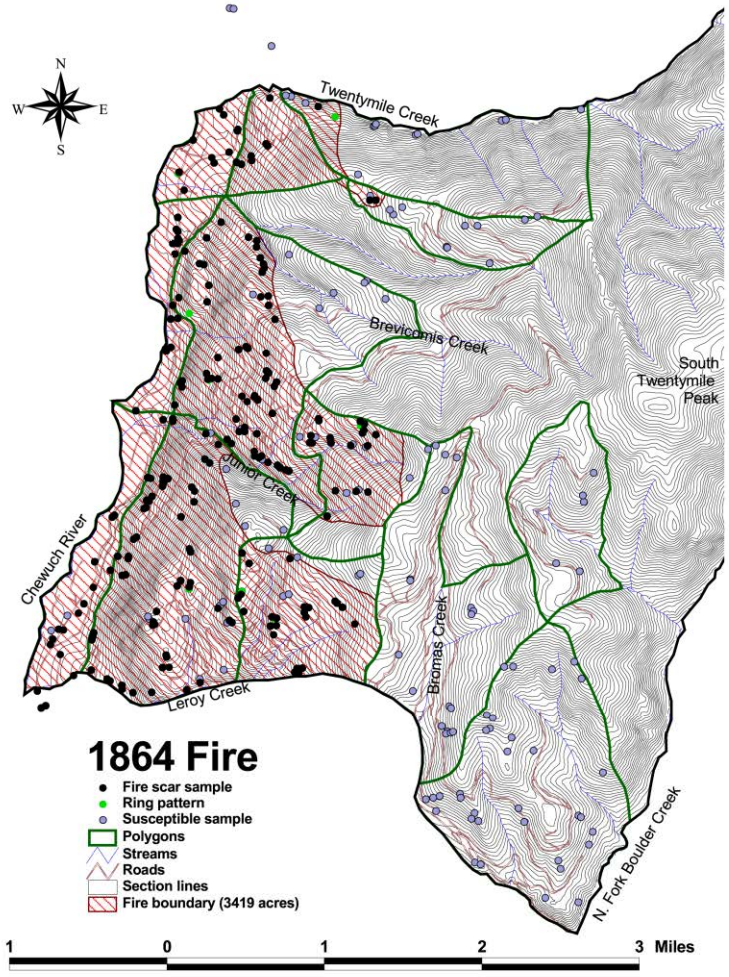
Twentymile Creek
Brevicomis Creek
South Twentymile Peak
Junior Creek
Chewuch River
Bromas Creek
Leroy Creek
N. Fork Boulder Creek
1859 Fire
Fire scar sample
Susceptible sample
Polygons
Streams
Roads
Section lines
Fire boundary (74 acres)
1 0 1 2 3 Miles


N
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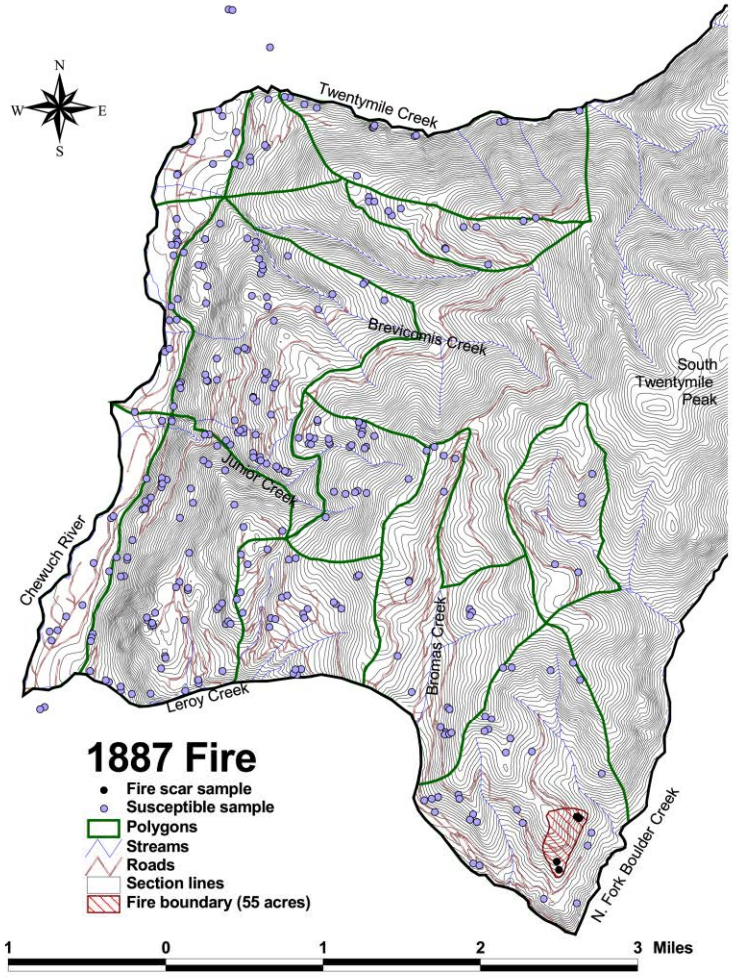
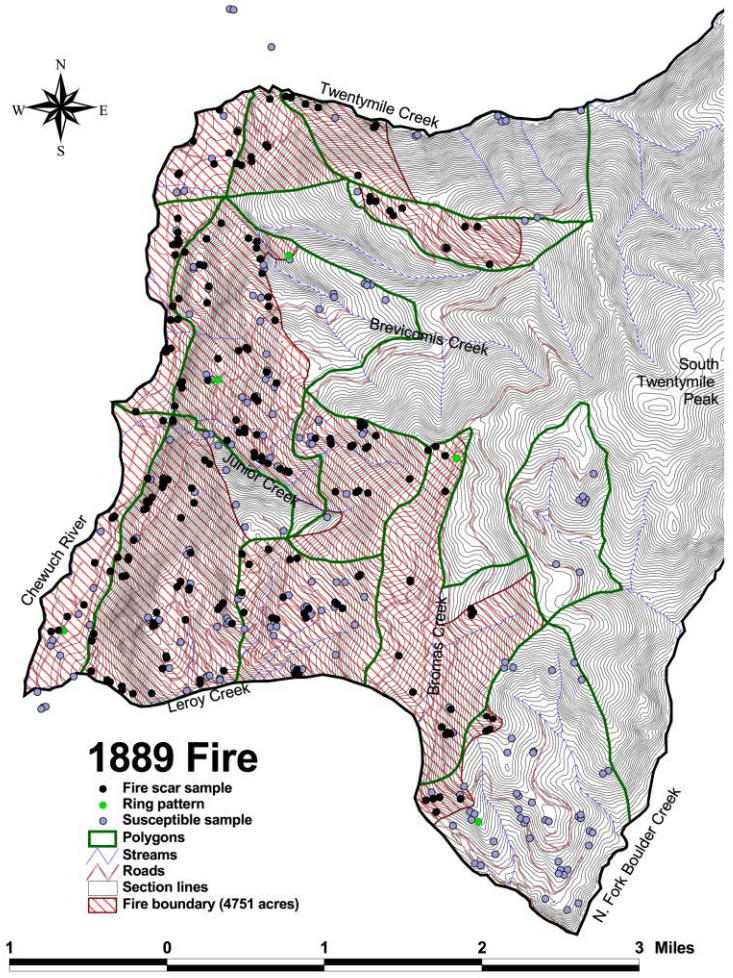
S
Twentymile Creek
Brevicomis Creek
South Twentymile Peak
Junior Creek
Chewuch River
Bromas Creek
Leroy Creek
N. Fork Boulder Creek
1864 Fire
Fire scar sample
Ring pattern
Susceptible sample
Polygons
Streams
Roads
Section lines
Fire boundary (3419 acres)
1 0 1 2 3 Miles


N
W
E
S
Twentymile Creek
Brevicomis Creek
South Twentymile Peak
Junior Creek
Chewuch River
Bromas Creek
Leroy Creek
N. Fork Boulder Creek
1887 Fire
Fire scar sample
Susceptible sample
Polygons
Streams
Roads
Section lines
Fire boundary (55 acres)
1 0 1 2 3 Miles


N
W
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Twentymile Creek
Brevicomis Creek
South Twentymile Peak
Junior Creek
Chewuch River
Bromas Creek
Leroy Creek
N. Fork Boulder Creek
1889 Fire
Fire scar sample
Ring pattern
Susceptible sample
Polygons
Streams
Roads
Section lines
Fire boundary (4751 acres)
1 0 1 2 3 Miles